Upgrade or Migrate: the Effects of Fertilizer Subsidies on Rural Productivity and Migration

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Rural development programs often emphasize investments in agriculture, but farmers may prefer to divest and leave. I explore how input subsidy programs (ISP) affect two margins of structural transformation: agricultural technology upgrades and out-migration. I show that a large-scale Zambian ISP increased upgrades (+25pp) and out-migration (+5pp). Out-migration increased driven by short-term input resale and medium-term productivity gains. The presence of resale markets changes the evaluation of ISPs relative to common anti-poverty policies. I estimate a choice model and show that resales efficiently reallocate fertilizer making ISPs reach higher upgrades than revenue-neutral cash transfers while achieving similar incomes gains.

JEL: R23, O33, Q12
Key words: Input Subsidies, Structural transformation, Agricultural Productivity, Migration

Rural poverty reduction efforts often focus on improving agricultural productivity rather than facilitating migration to areas with higher productivity. Globally, $540 billion is invested in agricultural subsidies annually, which is nearly three times the amount dedicated to official development assistance (ODA) by OECD countries.[1] One of the most common forms of such interventions is input subsidy programs (ISPs), which are implemented to increase smallholder productivity by making agricultural inputs like fertilizer and seeds more affordable. Such ISPs are often criticized by economists who argue that they can lead to the overuse of subsidized inputs, distort markets (Anderson et al., 2013), and hinder productive migration, trapping individuals in unproductive, rural areas (Lagakos, 2020).

In this paper, I examine both the direct and unintended consequences of input subsidy programs, focusing on the case of Zambia. I find that while farmers use these subsidies to adopt more productive technologies, a less-anticipated outcome also emerges: the ISP leads to increased out-migration from targeted areas. These findings raise an important question: how should policymakers approach place-based agricultural subsidies when these policies also remove a barrier to migration?

This question is particularly pressing given the popularity of ISPs, which are favored by voters in many countries and are likely to remain central to development strategies in Africa, Asia, and beyond (Jayne et al., 2018; Anderson et al., 2013). I answer this question in three steps.

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[1] Source Organisation for Economic Co-operation and Development (2024).

First, I quantify the effects of Zambia's ISP on two key margins: upgrading of agricultural technology proxied by fertilizer adoption and migration, both of which could drive structural transformation. Second, I rationalize these findings by building a model where farmers make two choices: (i) whether to upgrade their technology and (ii) whether to send out-migrants. The migration option becomes available for many farmers because they can monetize the ISP using resale markets to fund migration. Finally, I estimate the model and compare the ISP, in the presence of a resale option, to popular anti-poverty programs: universal cash transfer,[2] cash transfers targeted to would-be ISP recipients, as well as to the effects of an ISP if resale was prevented. Through this counterfactual analysis, I explore the trade-offs a policymaker faces when trying to design effective interventions to reduce poverty. The insights from this structural approach offer new ways for policymakers to approach the design of anti-poverty policies when balancing productivity gains with migration opportunities.

The ISP is Zambia's largest agricultural program and the most significant direct transfer to farmers. In the early 2000s, it accounted for 45% of discretionary anti-poverty spending and 20% of the agricultural budget (Mason et al., 2013a). Zambia's ISP is a place-based industrial policy aimed at increasing agricultural production and decrease poverty. It provides smallholder farmers, who are part of cooperatives, with a limited number of vouchers that offer a 50% subsidy on fertilizer purchases. The ISP can impact farmers' income by either freeing up resources they would have spent on inputs or by increasing their productivity in agriculture. The ISP could therefore influence decisions beyond agriculture, such as migration. For instance, the additional income could make migration an affordable option, increasing out-migration. On the other hand, an increase in productivity could raise the opportunity cost of migrating, making farmers less likely to leave.

In the first part of the paper, I use a representative panel of Zambian smallholder farmers from 2000 to 2008 to estimate a difference in differences and quantify the ISP's effects on farmers' upgrading and migration decisions. I use the variation in policy rollout over time and across regions, which serves as a natural experiment (Callaway and Sant'Anna, 2021). While there could be concerns about selection into the subsidy program that might challenge the post-parallel trends assumption,[3] the nature of the policy rollout suggests these concerns are minimal. Nonetheless, to further ensure the robustness of the estimates, I implement a two-stage (instrumented) difference-in-differences approach. In the first stage, I predict the exogenous part of treatment assignment using two instruments: a measure of political clientelism and a fertilizer supply shifter. In the second stage, I estimate a difference in differences with the predicted treatment groups using Callaway and Sant'Anna (2021).

I find that the ISP had transformative effects on targeted areas, with substantial direct impacts on agricultural productivity and indirect impacts on out-migration. The ISP, which benefited 20% of households in treated areas, increased the share of households using fertilizer

[2] I later refer to this universal cash transfer as a universal basic income

[3] For example, if some areas received the subsidy earlier due to proximity to cities or higher need.

by 25 percentage points (314%), resulting in a 257 kilogram per hectare (17%) increase in yields. Surprisingly, the subsidy also increased the share of households sending members to out-migrate, with an additional 5 percentage points (+16%) increase in the number of households sending out-migrants. These findings on out-migration are significant, especially compared to Bryan et al. (2014), who found in Bangladesh that a subsidy aimed at encouraging out-migration during the lean season induced an additional 22 percentage points of households to send out-migrants. I find no effect on in-migration into areas that received the subsidy, as indicated by the probability of hosting additional members in households. Overall, this transformation of rural areas following the introduction of the ISP led to a 25% increase in net income for households in areas where the ISP was available.

Within treated areas, the effects of the subsidy are heterogeneous, especially since farmers have the option to resell the vouchers they receive. In the short term, (i) farmers who received the ISP can sell part (or all) of their vouchers to fund migration. This may explain why up to 45% of households that received the subsidy had out-migrants. (ii) Farmers who did not receive the ISP in treated areas can still purchase vouchers from resellers. Despite resales being prohibited, the data shows that 3% to 5% of non-recipient households report using fertilizer from the ISP, suggesting that such transactions are common. For households that use their vouchers to invest in agriculture, productivity and income may increase in the medium term, allowing them to finance migration later. Roughly 51% of households that upgraded their farming technology in 2004, without initially sending migrants, had out-migrants by 2008.

The transformative effects of the ISP on technology upgrades and out-migration can be attributed to four key mechanisms. First, there is strong evidence of active resale markets, allowing farmers to sell their vouchers and migrate in the short term. These farmers also reinvest the proceeds in productive assets—such as livestock and machinery—as well as their children's education. Second, migration occurs in both the short- and medium-term. This suggests that the ISP helps some farmers overcome credit constraints to migrate immediately, while others use their increased productivity to fund migration later. Specifically, in the year they receive the subsidy, an additional 3 percentage points of households send out migrants, indicating a relaxation of credit constraints. Within four years of the subsidy's introduction, an additional 8 percentage points of households migrate, consistent with structural transformation patterns. Third, I show that it was the voucher migrated at higher rates, indicating that the direct beneficiaries of the ISP were the ones cashing out and moving, rather than non-recipients leaving after being priced out of agriculture by the ISP. Lastly, there is suggestive evidence of specialization within and across households. More productive farmers remained in ISP areas to upgrade their agricultural practices in the short run, while those with higher returns in out-migration leave.

An important finding from the natural experiment is that ISPs affect far more than just agricultural outcomes; they also play a crucial role in relaxing credit constraints for farmers who might otherwise be confined to agriculture. However, the natural experiment does not provide enough insight into resale markets to guide effective poverty-reduction policies. In the second and third parts of the paper, I develop and estimate a model and simulate counterfactual policies to understand how policymakers can best incorporate important margins of farmers' decisions to reduce poverty, especially in contexts where in-kind transfers can be converted into cash and place-based programs may drive migration.

In the second part, I build a model where farmers choose both their agricultural technology and their level of migration. I include resale markets where farmers can either sell or buy ISP vouchers. The model endogenizes fertilizer prices and accounts for the quantity of fertilizer made available through the ISP. I also incorporate a binding credit constraint that prevents farmers from borrowing against future migration income. Though static, the model captures migration either occurring immediately as a result of relaxed credit constraints or in the medium term due to productivity gains. This structure reflects the findings from the natural experiment, where migration is driven both by farmers monetizing their ISP vouchers in resale markets and by productivity increases over time. In this model, farmers facing a binding credit constraint can use resale markets to generate the liquidity needed to fund migration. Meanwhile, the most credit-constrained farmers may be better off investing in agricultural technology first, using the surplus generated in the medium run to eventually fund migration.

In the third part, I estimate the model using Maximum Likelihood and compare the effects of the current subsidy program with resale markets to three revenue-neutral counterfactual policies. The results suggest that, due to existing frictions, an ISP with resale markets may be the preferred policy to increase both food production and income. The first counterfactual policy enforces a ban on resale markets, reducing the number of households sending migrants (-4.71%) and substantially lowering the propensity to upgrade their farming technology (-64.54%). This happens because farmers can no longer monetize their vouchers or split them across households. The second counterfactual policy provides cash transfers to the 8% of households originally targeted by the subsidy, which results in lower upgrade rates (-70.87%) and marginally lower out-migration rates (-5.32%) because a cash transfer by design prevents efficient resource reallocation to more productive farmers. The third policy gives lower amounts of cash to all farmers in treated areas, which decreases the extent of migration (-5.32%) and has a large negative effect on technology upgrades (-79.87%) compared to the baseline ISP with resale markets. The smaller cash amounts are not enough to significantly relax credit constraints and influence migration.

In the model, an ISP with resale markets outperforms the counterfactuals through four channels. First, the increased availability of fertilizer from the ISP reduces prices for all farmers in treated areas, providing an advantage over cash-transfer alternatives.[4] Second, like cash transfers, resale markets for vouchers provide liquidity to ISP recipients, helping them overcome credit constraints and make optimal choices. Furthermore, resale markets allocate inputs to more productive farmers, thereby increasing allocative efficiency—cash ends up with ISP recipients, and inputs end up with productive farmers. Third, the ability to split vouchers among

[4] In contrast, Cunha et al. (2019) find an increase in prices resulting from cash transfers.

multiple farmers creates a multiplier effect for technology upgrades, offering an advantage over an ISP without resale markets. Finally, the effects of the ISP extend into the medium term, as increased fertilizer availability and farm productivity create an income effect that further influences households' migration decisions.[5]

Assessing the overall welfare implications of these policies in an environment with market failures and out-migration is complex. A back-of-the-envelope calculation suggests that median and mean farming revenues are similar for both the current ISP and the targeted cash-transfer program. While migration rates are statistically equivalent across the counterfactual policies, the Zambian ISP, with its informal resale market, leads to higher in-farm production. This result highlights the trade-off policymakers face between using an ISP with resale markets to increase food production across the country and implementing a cash-transfer program that results in a modest income increase for households in treated areas.

The paper adds a unique contribution to our broad understanding of ways in which input subsidy programs transform rural economies and affect the out-migration decisions of farmers in targeted areas. It further provides tools to understand how policymakers can leverage a better understanding of these margins of farmers' decisions to better design anti-poverty policies.

Specifically, this paper contributes to three strands of literature. First, I contribute to a large literature that explores drivers of migration and show that even when targeting agricultural upgrades, ISPs can have large impacts on migration. I show that migration occurs in two ways: in the short run through fertilizer resale markets or in the medium run by generating a surplus from using the subsidized inputs on their farms. Previous studies tested the presence of either productivity-induced or liquidity-induced migration, making it difficult to distinguish between short-term credit drivers of migration (Gazeaud et al., 2023; Cai, 2020; Bazzi, 2017; Angelucci, 2015)[6] and long-term improvements in technology that fund migration (Bustos et al., 2016; Gollin et al., 2014; Ngai and Pissarides, 2007; Lewis et al., 1954). I quantify the relevance of these two channels, first by using the natural experiment that allows me to decompose short- and medium-term migration, and then by shutting down different channels in the structural estimation of counterfactuals. I show that, although medium term structural change is important in explaining migration, credit constraints affecting decisions in the short run are nevertheless binding for many farmers.

Second, I contribute to the literature on anti-poverty programs in economically poor countries. I build on a literature on rural markets and explicitly model well-documented market frictions in these areas. I consider a set of market frictions—fixed costs—that lead the ISP to affect migration and upgrade margins at higher rates than previously found (Carter et al., 2021; Jayne et al., 2018; Schmitz et al., 1997). The structural estimates indicate that unconditional cash transfers may not be as efficient in achieving specific policy objectives such as increasing

[5] In this model, I focus on agriculture and migration; however, in reality, cash could be invested in other productive activities, such as business creation, which is not captured in this analysis.

[6] Alfano and Görlach (2024) measure how different policies affect climate-adaptation induced migration.

in agricultural productivity because they do not address the costs associated with upgrading. By contrast, an ISP with resale markets can efficiently reallocate transfers by sorting beneficiaries based on their constraints. In the early stages of Zambia's ISP, the large transfer of fertilizer was documented as being too large for many of the smaller landholders, leading to a snowball effect in which one transfer could benefit multiple farmers when recipients sold a portion of their vouchers. Despite previously documented inefficiencies of the ISP (Jayne and Rashid, 2013; Xu et al., 2009), I show that only ISPs with resale markets result in efficiency gains and higher levels of both upgrading and migration compared to cash-transfer programs.

Finally, I contribute important insights to a growing literature documenting how individuals adjust to mitigate undesirable aspects of policies. I show that an industrial, place-based policy, which is predicted to leave unproductive farmers stuck in agriculture in partial equilibrium, can increase migration. This occurs when resale markets allow farmers to exchange an ISP voucher for cash, which they can use to fund migration. Essentially, the voucher program becomes a mix of a cash transfer for those who resell and in-kind transfers for those who do not. This finding is in line with work by Banerjee et al. (2023) and Aker (2017), who show that when transfer programs fail to meet recipients' needs, they use rotating savings and credit associations (ROSCAs) or tradable goods to obtain the cash and goods they need. I also find that resale markets allow farmers with higher returns in non-agricultural activities to sell their vouchers to those who can use them for fertilizer-intensive farming, generating income for migration. Resellers use private information to sell their vouchers, improving the program's overall allocative efficiency. Previous studies have shown that these resale markets are important; they emerge in settings where beneficiary types are unobservable to the planner and when efficiency improvements are possible by reallocating transfers (Giné et al., 2022; Ravallion, 2021; Gadenne et al., 2024).

The remainder of the paper proceeds as follows: Section 1 presents the Zambian context, the data, and the empirical strategy for the natural experiment. Section 2 presents the direct effects of the ISP on upgrading and the indirect effects on migration using the natural experiment. Section 3 discusses potential mechanisms that generate these results. Section 4 generalizes these findings with a selection model. In Section 5, I estimate the choice model, compare an ISP with resale markets to other anti-poverty policies, discuss optimal policies, and conclude.

1 Context, data, and natural experiment

In this section, I describe the relevant institutional details of the Zambian agricultural system, the panel of post-harvest surveys I use in the paper, and the estimation strategy for the natural experiment. I examine the effects of the ISP on farming households' decisions to upgrade their agricultural technologies and their decision to migrate or send members to migrate. I focus on migration because it represents the extreme case of divestment from agriculture and has less measurement error than the intensification of non-agricultural rural activities. I use the ISP as

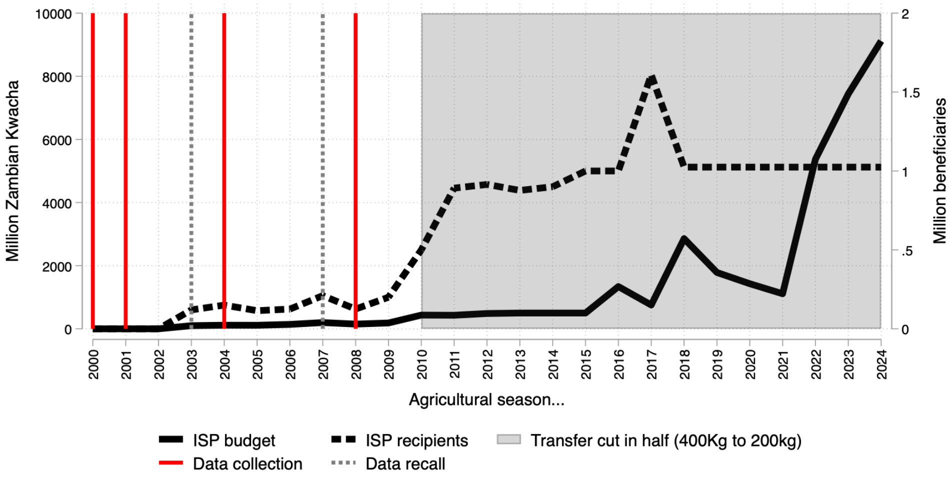


Figure 1: Time series of the number of intended beneficiaries, and costs of the ISP

Notes: This figure plots the evolution over time (from 2004 to 2024) of the budget and beneficiaries of the Zambian Input Subsidy Program (ISP). The solid-line series represents the budget allocated by the Ministry of Agriculture and Cooperatives to the ISP, corresponding to the left-hand y-axis. The dashed-line series represents the number of recipients of the ISP, corresponding to the right-hand y-axis. Solid vertical lines indicate the years of the post-harvest panel, while dashed vertical lines represent the years of recall for fertilizer use. The data source for this plot is the Ministry of Agriculture and Cooperatives of the Republic of Zambia.

a source of exogenous variation in liquidity in the short run and agricultural productivity in the long run, to understand how households' labor allocation decisions change because of the ISP.

1.1 The Zambian fertilizer input subsidy program

In 2001, the Zambian agricultural sector contributed 16% to the country's GDP; the sector employed about 72% of the Zambian labor force, with remarkably low productivity levels (Ritchie and Roser, 2020; Govereh et al., 2009). In response to low fertilizer take-up, the Zambian government, along with a dozen other African countries, pledged to increase the use of fertilizer and set up farmers' cooperatives (Jayne et al., 2018).

In the 2002-2003 agricultural season, Zambia launched the Fertilizer Support Program (also called FSP) aimed at increasing fertilizer use in the production of maize.[7] In its initial years, the FSP accounted for 55% of the Zambian government's agricultural poverty reduction budget, implying that poverty reduction was a key underlying objective (Mason et al., 2013a). In the 2003-2004 agricultural season, the program provided a voucher that could be used to receive a 50% rebate on 400 kilograms of fertilizer and 20 kilograms of seeds to each recipient farmer.[8] Farmers are required to pay upfront, in cash, the total value of the voucher, which is 50% of the value of the fertilizer they acquire. In the remainder of the paper, I focus on the 2003-2004 agricultural season as the main treatment season.

Area selection: In the 2003-2004 season, the ISP reached 8% of smallholders (see Figure

[7]The FSP renamed Farmer Input Support Program (FISP), replaced a much smaller Fertilizer Credit Program.

[8]That is, a total of eight 50 kg bags of fertilizer, four of them containing basal fertilizer and four containing top-dressing fertilizer, the amounts the government recommends be used on one hectare of maize (The World Bank, 2010). In the 2009-2010 season and afterward, the fertilizer supply was halved. For completeness, the voucher was later increased to 60% then 76% starting in the 2010-2011 season.

1). Fertilizer for the program was imported by two suppliers selected through a national bidding process.[9] Upon arrival in the country, inputs were stored in central depots and then transported by local transporters to satellite depots for distribution to farmers. This distribution system operated independently of the existing private provider networks. These providers faced various logistical challenges, including poor coordination, which resulted in a lack of geographic targeting, which has been a point of criticism within the FSP (Resnick et al., 2016). However, recipients receiving the ISP had on average higher fertilizer usage rates. Despite limited targeting, Mason et al. (2013) finds evidence of political clientelism, where areas benefiting from ISP were more likely to be in regions that had supported the incumbent party.[10]

The expansion of the program to new areas was often limited by budget and logistical challenges, primarily because only two companies were responsible for distributing fertilizer nationwide. In the areas served, the ISP is implemented through cooperatives. This aspect of the program was designed to encourage the formation of cooperatives, which were uncommon in Zambia prior to the ISP.[11] Cooperatives make it easier for the country's agricultural authorities to reach farmers and are intended to enhance production, improve marketing, and increase the technical efficiency of smallholders (Bernard and Taffesse, 2012). The cooperatives involved in the subsidy program are preselected by District Agriculture Committees (DACs), and only farmers who are members of these cooperatives are eligible to participate. When the ISP first launched (which is the period covered by this study), it was intended to last for only three years, with recipients eligible to receive the subsidy for a maximum of two seasons.

Farmer selection: Farmers within cooperatives are selected by board members, in collaboration with local extension officers from the Ministry of Agriculture and Cooperatives (MACO) (Mason et al., 2013a). The program targets smallholders with landholdings between one and five hectares, and recipients must be members of a cooperative, which requires paying a small fee (Mason et al., 2013a). As a result, farmers who received the subsidy were generally wealthier than those who did not (The World Bank, 2010). Farmers participating in the program receive vouchers that can be redeemed at designated ISP distribution points. These vouchers allow farmers to purchase fertilizer at half the cost. The median pecuniary value of the subsidy in 2004 is US$100 out of the $200 total value of the fertilizer, in a setting where more than four out of six households have no net income (i.e. their costs are higher or equal to their income. See Figure A.7 for the distribution of net income for those with a net income).

Timing of the program: The ISP began during the 2002-2003 agricultural season but was relatively small in its first year.[12] Farmers must procure inputs each agricultural season, meaning the program effectively resets each year. Vouchers are only valid for one agricultural season

[9] Omnia Fertilizer Zambia and Nyiombo Investments consistently won these contracts (Mason et al., 2013a).

[10] I leverage these findings of political clientelism to test the robustness of the empirical strategy in Section 2.4.

[11] The ISP itself played a role in the creation of cooperatives, primarily established to help farmers access agricultural inputs (Mason et al., 2013a). This requirement stems from the Maputo Declaration, in which the Zambian government committed to fostering the creation of farmers' cooperatives, which were largely nonexistent before the ISP (Jayne et al., 2018; Policy Monitoring and Research Center, 2015).

[12] The ISP is ongoing, but it has undergone significant redesigns over the years.

and do not carry over. As a result, any unused vouchers in a given year are forfeited and cannot be used in the following season.

The context of the ISP offers three key advantages for informing the estimation strategy. First, the ISP's supply chain, which operates independently from the existing commercial network, faces significant logistical challenges, limiting the government's ability to geographically target areas based on agricultural returns. As noted by Resnick et al. (2016), the ISP did not specifically target regions to improve agricultural outcomes or reduce poverty, a common criticism of the program. Instead, at the margin, the ISP targeted communities that supported the incumbent. This lack of targeted selection reduces the likelihood of endogenous selection, which could threaten the parallel trend assumption. Second, the arbitrary selection of newly formed cooperatives, combined with budget caps (see Figure 1) and logistical constraints, introduced year-to-year variation in which areas received the subsidy. This variation led to changes in the list of treated areas over time. Third, farmers are offered participation in the ISP by representatives from the Ministry of Agriculture and Cooperatives (MACO) and community-level cooperative boards. While this targeting creates selection at the household level, it does not necessarily mean that the most productive farmers receive the ISP. This implies that it may still be optimal for farmers to transfer the vouchers to more productive farmers within the area.

For the estimation strategy, I consider the area as the unit of treatment for two reasons: (a) treated farmers may be on different productivity trajectories than non-treated farmers within the same area, and (b) informal transfers of fertilizer across households within areas may complicate household-level treatment assignment. Therefore, once an area receives the ISP, I assume logistical barriers are overcome, making the program potentially available to the area in subsequent years. While there may be instances where no smallholders in the area participate in a given year, once an area is treated, I treat it as being continuously eligible for the program, even if it does not show up in the data for specific years. By 2008, around 30% of community leaders reported some rotation in recipients, with different farmers receiving the ISP each year.

Table A.8 in the Appendix confirms that some areas appear to be treated in certain years but not consistently over time. As such, the estimation will follow an intent-to-treat (ITT) approach, considering an area treated once the program becomes available there, even if individual participation fluctuates.

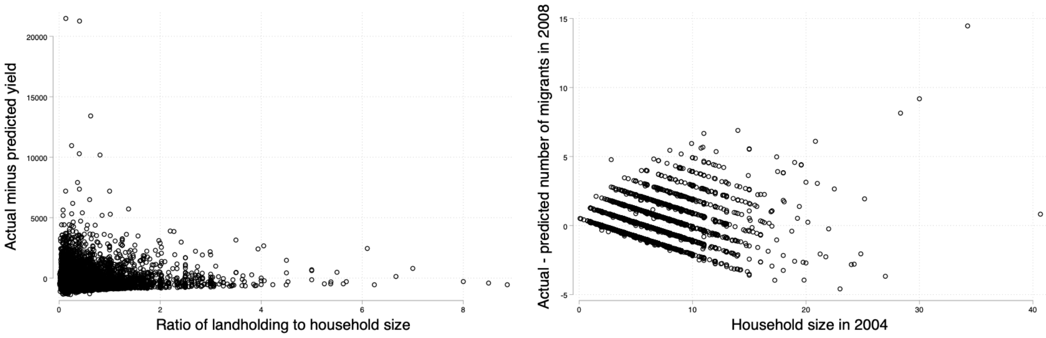
Other concurrent programs: The ISP was the largest agricultural budget item on the government budget (see Table A.6). However, the Zambian government launched the Zambia Youth Empowerment Fund (ZYEF) in 2006, aimed at promoting economic empowerment by supporting income-generating activities for Zambians aged 16 to 30. The fund is designed to provide cooperatives with access to financial resources, encouraging youth participation in entrepreneurial and productive ventures. However, since this study focuses on the impact of the ISP on beneficiaries in 2004, the introduction of the ZYEF in 2006 does not significantly influence the estimation in this context, at least not in the short run.

1.2 Productivity dispersion at baseline and outside options

Smallholders are the majority of farmers in Zambia, but their productivity in agriculture varies vastly. The left panel of Figure 2 plots the difference between the linear projection of yields from Equation 1 (which regresses yields on landholdings and labor inputs) and the actual yields against the ratio of landholding to household size. If individuals with similar household sizes and landholdings are equally productive, their yields should be similar, and the difference between their predicted and realized yields (y-axis of the left panel of Figure 2) should not be large. Instead, there are substantial variations on the y-axis, and these variations occur across all ratios of landholding to household size (x-axis).

$$\text{Yields}_{2000,i} = \alpha + \beta_1 \text{land}_{2000,i} + \beta_2 \text{HHsize}_{2000,i} + \epsilon_i \tag{1}$$

$$\text{Migrants}_{2008,i} = \alpha + \beta_1 \text{land}_{2008,i} + \beta_2 \text{HHsize}_{2004,i} + \epsilon_i \tag{2}$$



(a) Dispersion in yields
1999-2000 season cross section

(b) Dispersion in migrant counts
2007-2008 season cross section

Figure 2: Dispersion of outcomes for farming households

Notes: This figure plots the dispersion of yields Panel (a) and in migrants Panel (b). The left panel plots the difference between the linear projection of yields from Equation 1 (which regresses yields on landholdings and labor inputs) and the actual yields against the ratio of landholding to household size. The right panel plots the difference between the actual number of migrants per household and the linear projection from Equation 2 (which regresses the number of migrants on landholding and household size).

While there could be numerous reasons for the dispersion in outcomes shown in Figure 2, the large dispersion in outcomes for farmers suggests potential gains from reallocating inputs (labor and land) for the least productive farmers, which could be facilitated by some farmers migrating away. The right panel of Figure 2 illustrates the difference between the actual number of migrants per household and the linear projection from Equation 2 (which regresses the number of migrants on landholding and household size—analogous to Equation 1). The figure shows that by the end of the panel, many households have divested from agriculture to some extent.

1.3 Data, productivity dispersion, and outside options

Data

I use a panel of 6,922 rural households in Zambia. The data were collected between 1999 and 2008 by the Zambian Central Statistical Office and the Zambia Food Security Research Project at Michigan State University. This panel contains four waves. The 1999-2000 Post-Harvest Survey (PHS) serves as the baseline with three subsequent agricultural seasons: 2000-2001, 2003-2004, and 2007-2008. Of the 6,922 rural households surveyed in 1999-2000, 4,288 were surveyed every year of the panel. The PHS is a representative survey of farmers whose landholdings are of small or medium size—i.e., the survey is representative of rural households in the 1999-2000 season.[13]

The smallest sampling unit of the panel is a standard enumeration area (SEA), and twenty households are sampled within each of those SEAs. SEAs were drawn proportional to number of households from the 1990 Census of Population. There are one to seventeen villages contained in those SEAs, with ten villages per SEAs being the 80$^{\text{th}}$ percentile.[14]. In what follows, I refer to the SEA as an area.

Measurement

In this paper, I primarily focus on two features: agricultural technology upgrades, proxied by fertilizer adoption, and migration. I measure these in the following ways:

Upgrade: To measure agricultural technology upgrades, I use both a binary and a continuous measure. For the binary measure of upgrade (the extensive margin of upgrade), I use self-reported information on whether households used any fertilizer, focusing on households transitioning from not using fertilizer to using any quantity fertilizer. For the continuous measure of upgrade (the intensive margin of upgrade), I aggregate all quantities of fertilizer used across various sources, such as the ISP, commercial markets, and other alternative means.[15] To measure yields, I consider the quantity of maize produced per hectare of land owned, including both cultivated and fallow lands.

Migration: I construct several measures to capture the extensive and intensive margins of migration. First, I measure the out-migration of the entire household, *en masse* (the extensive margin of household migration). This binary decision is tracked by whether households moved out of the area; households that exit the sample for other reasons are not counted as migrant households. I use information on whether the household "moved out of standard enumeration area boundaries." Panel B2 of Table A.4 in the Appendix lists the two survey statuses that are

[13] Panel A of Table A.4 in the Appendix details the variable construction and the sampling frame.

[14] See breakdown of the number of villages in SEAs in Table A.2)

[15] These alternative means include farmers using a few other sources such as left-over fertilizer from previous years or gifts. Quantities stemming from these sources are small in comparison to the quantities used that were from the ISP and commercial markets.

used to define whether a household has migrated out of an area or not.[16] This definition of a migrant household does not include households that were not interviewed because they were dissolved, refused to answer or for which there was a failure to make contact. This definition ensures that we are capturing the narrowest definition of household out-migration.[17]

Second, I measure individual migration, which includes households hosting new members (in-migration) and sending members out (out-migration), capturing extensive margins. The definition of out-migration includes migration for work, marriage, education, and moving to other relatives. The measure of in-migration includes adult members who were not previously in the household, those who joined the household via marriage, and returnees. Intensive margins consider the number of migrating members. There is a high degree of confidence in the information used for individual migrants because the survey asks remaining members about the migrants' reasons to migrate. Table A.5 lists the reasons for individual migration —both in-migration and out-migration —and their shares.[18] Table A.5 also shows the total number of out-migrants and of in-migrants: the total number of out-migrants each year of the panel outnumbers the total number of in-migrants 3:1. Measures of individual out-migration do not account for individuals who left the households but stayed in the area. All individual out-migrants used in the data are actual migrants who left the area—as reported by the household member who answered the survey. For the proxy measure of in-migration, these data measure members joining the households. These in-migrants may have come from within the area.

Treatment: The primary level of treatment is at the area level, but I also show results at the household level as robustness checks. I consider an area treated if at least one of its households receives the fertilizer through the ISP; on average, treated areas had 20% of its households receiving the subsidy. For the ISP, I create an indicator variable for households in areas receiving the subsidy, and a variable for the cash amount received, based on the quantity acquired through the program (FRA) and the subsidized share of the costs to farmers (0.5 in 2004 and 0.6 in 2008). The panel contains observations from the following agricultural seasons: 1999-2000, 2000-2001, 2003-2004, and 2007-2008. There are no surveys in the season 2002-2003 and 2007-2008 agricultural seasons, however I can identify the treatment status of households (i.e., whether they received the ISP) based on respondents' recall in the 2003-2004 and 2007-2008 agricultural seasons respectively. Out of the 78 areas that received the ISP in 2004, 33 (42%) continued receiving the subsidy in 2008, and 55 areas received the ISP in 2008 for the first time.[19] Although there are only two data points after the introduction of the subsidy (for

[16]The two statuses used to define a migrant household are "Moved out of SEA" and "Completed [the survey] after moving to another SEA", the latter only occurred in 2008, when the survey team tracked movers.

[17]While some households may have moved out of the standard enumeration area but stayed in the close by — which can be counted as measurement error. However, given the size of the standard enumeration areas (see Table A.2), it these errors should be small. Furthermore, there are no reasons to believe that these errors are not classical.

[18]Marriage is the leading reason for out-migrating, followed by miscellaneous reasons and work. Marriage is a documented economic reason to out-migrate (Bau et al., 2023). However, I ran alternative specifications excluding marriage departure from the definition of out-migration, and the results stay qualitatively similar.

[19]For more details on the breakdown of treatment, see Table A.8 in the Appendix.

the 2003-2004 and 2007-2008 panel waves), I observe whether households received the subsidy in the previous year (i.e., in the 2002-2003 and 2006-2007 agricultural seasons). In practice, the dataset only misses treatment status in the 2004-2005 and 2005-2006 agricultural seasons, however, for the estimation I do not make use of data from recall as measurement errors may be systematically larger for recall years. Table A.3 in the Appendix shows descriptive statistics on intensive margins of migration and the ISP. In 2001, no household received the ISP. Migration rates were highest for households that received the ISP, and the rates increased over time.

1.4 Empirical strategy: a difference in difference at the area level

I use the gradual roll-out of the ISP by the Zambian government to estimate the causal change in behavior across upgrading and migration outcomes for households that received the subsidy in 2004. Notably, some areas received the ISP in 2004, others by 2008, and some never did during the study period.[20] To take advantage of the staggered roll-out of the subsidy, I use the estimation strategy from Callaway and Sant'Anna (2021). The analysis focuses on three groups: (i) areas that never received the subsidy (pure control, $c = \infty$), (ii) areas that received the subsidy in 2004 (early treatment, $c = 2004$), and (iii) areas that received the subsidy in 2008 (late treatment, $c = 2008$). The primary focus of the analysis are the early treatment areas ($c = 2004$), which are the areas for which I show results.

An area is considered treated if at least one household in the area received the subsidy. Therefore, the difference-in-differences estimates represent an intent-to-treat effect (ITT), a lower bound for the actual treatment-on-the-treated effect. I estimate the following equation at the household level, with treatment varying at the area level:[21]

$$Y_{h,t}^{c} = \alpha^{c} + \sum_{c=2004}^{2008} \beta_t^c \mathbb{1}_{\{t \geq c\}} + \gamma_h X_h^{2001} + \nu_h + \nu_t + \epsilon_{h,t} \tag{3}$$

Where t is each year of the panel: 1999-2000, 2000-2001, 2003-2004, and 2007-2008. c represents the treatment cohort for the area: never treated ($c = \infty$), treated in 2004 ($c = 2004$),[22] or treated in 2008 ($c = 2008$). X_h^{2001} is a vector of household characteristics at baseline (in 2001), including household size, the migration status (*en masse*) of the household, the household's baseline score on a wealth index,[23] and whether the household used fertilizer at baseline, which controls for the fact that households that received the ISP tended to have higher baseline fertilizer use. ν_h and ν_t are the household and time fixed effects, respectively. $\mathbb{1}_{\{t \geq c\}}$

[20] Some farmers recall receiving the subsidy during the agricultural seasons of 2002-2003 and 2006-2007. However, these recalls are not part of the classification for the treatment and control groups. Including the recall years in the classification would only impact 13 of the 279 treatment areas (see Table A.1) and may introduce non-classical measurement error.

[21] Notations follow Callaway and Sant'Anna (2021).

[22] Areas that received the ISP in both 2004 and 2008 are included in the 2004 cohort, with $c = 2004$.

[23] The wealth index includes ownership of basic household goods and appliances: bicycle, radio, motorbike, canoe, TV, car, truck, mill, pump, protected well, roof, wall, and door frame.

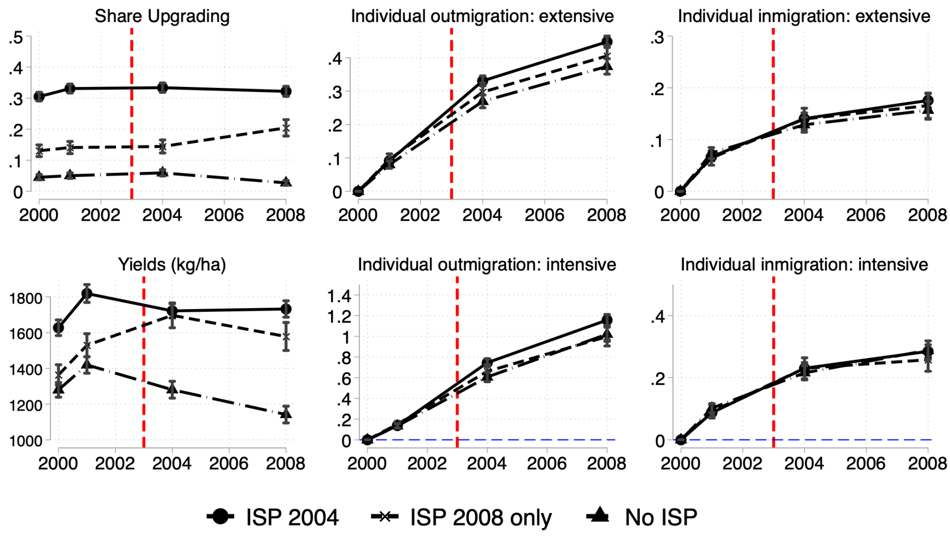


Figure 3: Raw time series of main outcomes

Notes: This figure plots the raw outcome over the panel years—between 2000 and 2008. Each raw outcome is plotted, aggregated at the year level, for the three treatment groups: areas that received the ISP in 2004 ("ISP 2004"), in 2008 but not in 2004 ("ISP 2008 only"), and those that never received the ISP ("No ISP"). The outcome variables are displayed in each graph's subtitle. The X-axis represents the years, and the Y-axis represents the outcome variables. A dashed vertical line indicates the year of the ISP introduction. The data spans the 1999-2000, 2000-2001, 2003-2004, and 2007-2008 agricultural seasons. Confidence intervals are plotted for each year.

is a binary variable equal to one for any year following the year an area receives the ISP. $Y^c h, t$ measures outcomes that capture whether a household upgraded its agricultural technology, either by starting to use fertilizer (binary decision) or by increasing the amount of fertilizer used (continuous decision), both of which can impact yields. It also measures changes across five migration margins: whether there was in-migration or out-migration within a household (extensive margins), changes in the number of in-migrants or out-migrants (intensive margins), and whether the entire household out-migrated (*en masse*). Standard errors are clustered at the area level.[24] For β_t^c to provide unbiased estimates of the causal effect of the ISP on the outcomes, two key assumptions must be satisfied: (i) conditional parallel trends must hold, and (ii) there must be no anticipation effects.

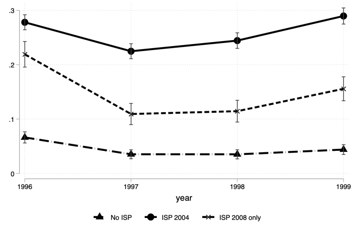
Conditional parallel trends: Figure 3 presents raw averages at the treatment group level, showing the share of upgraders, the share of migrants at both the extensive and intensive margins, and yields from 2000 to 2008. Observations before the dashed vertical line represent the pre-trends. The plots reveal unconditional parallel trends prior to the introduction of the subsidy, followed by a divergence after its implementation in the 2002-2003 agricultural season.

I use repeated cross-sections of the Post-Harvest Survey (PHS) between 1996 and 2000 to further investigate the parallel trend assumption in the difference-in differences estimation above. This sample is different from the panel used for the main analysis but offers an insight

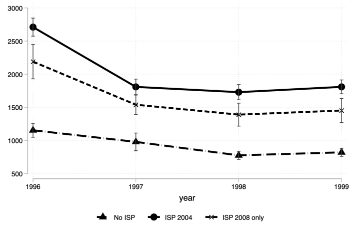
[24] Following Sant'Anna and Zhao (2020) and Callaway and Sant'Anna (2021), I estimate Equation 3 using a doubly robust difference-in-differences estimator based on stabilized inverse probability weighting and ordinary least squares.

into the parallel trends. Panel A of Figure 4 shows the evolution of raw averages over time (from 1996 to 1999) of different treatment groups. Trends are visually parallel prior to the introduction of the subsidy for the quantity of fertilizer used (except perhaps for a slight change in trend between 1996 and 1997),[25] and the quantity of maize harvested. Panel B of Figure 4 presents the placebo test estimating Equation 3 on the repeated cross section and using 1996 as the placebo treatment year.[26] It shows no significant deviation from the parallel trend, except for the first year of the panel. In the subsequent years (which are the three years preceding the panel used in the main estimation), all three outcomes are not significantly different from zero. While the significance in the first year may raise concerns, differences in sampling and population characteristics may explain this one-year deviation. The fact that this deviation occurs in the earliest year of the data may help alleviate these concerns.

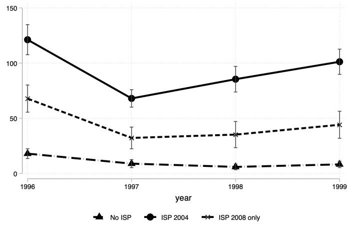
Panel A: Raw time series of main agricultural outcomes



(a) Upgraders

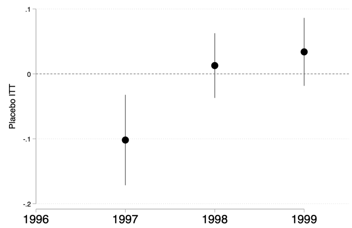


(b) Kilograms of maize harvested

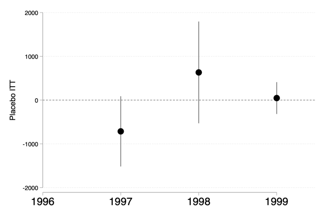


(c) Kg fertilizer used

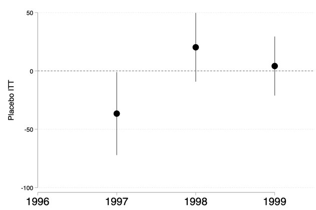
Panel B: Placebo estimates for difference in differences



(d) Upgraders



(e) Kilograms of maize harvested



(f) Kilograms of fertilizer

Figure 4: Out-of-sample parallel trends for agriculture outcomes by areas

Notes: The figure plots historical data using prior cross sections (out-of-sample) of the Post-Harvest Survey (PHS) from 1996 to 1999. In Panel A: each graph plots the yearly average of one variable (given in each graph's subtitle) for areas that never received the subsidy, areas that received the subsidy in 2004, and areas that received the subsidy by 2008. The term "upgraders" refers to households that used any fertilizer on their farm. Each marker represents the average of the variable for the year. The 2004 treatment cohort is the main treatment group. The control group is made up of a combination of the 2008 treatment cohort and never treated areas. Panel B of 4 presents the placebo regression using 1996 as the placebo treatment year and estimating Equation 3.

No anticipation: Mason et al. (2013a) and anecdotal evidence suggest that logistical issues and clientelism surrounding the program limited the ability individuals had to predict

[25] The quantity of fertilizer used by farmers is subject to greater volatility because I pool together data on all types of fertilizer. The amount of fertilizer required per acre varies, depending on the type of fertilizer used (basal and top dressing). Some types must be used in greater quantities; some types must be used in smaller quantities.

[26] A key distinction from the estimation of the main difference-in-differences estimation is that I use a random coefficient model instead of a panel estimation. This approach allows me to account for the fact that the placebo test is conducted on a repeated cross-section rather than a panel dataset.

areas and households that would receive the ISP.[27] In Section 2.4, I estimate an instrumented difference-in-differences using exogenous variation in treatment driven by political clientelism and supply-side conditions in the fertilizer market to identify variation in the likelihood of receiving the subsidy. The results are consistent in sign and magnitude with the main estimates.

2 Results of the natural experiment: effects of the ISP on upgrading and migration

In this section I present the resulting change in agricultural upgrading and migration decisions induced by the ISP. First, I show the causal impacts of the ISP on agriculture-specific outcomes, in line with prior research on subsidies for agricultural upgrades (Carter et al., 2021). Second, I show important and novel causal effects of the ISP on household migration decisions. I find that both upgrading and migration increased substantially as a result of the ISP.

2.1 Results: direct effects on upgrading

Prior to looking at migration outcomes, I show that the subsidy program, which was designed to move the needle on the adoption of fertilizer, did indeed improve agricultural outcomes.

Table 1 (and A.11 for more details) shows the difference-in-differences results on agricultural technology upgrades (fertilizer use), household member inflow (labor in farms), and maize yields in areas that received the subsidy in 2004.[28]

The likelihood of upgrades increased in areas that received the subsidy by an aggregate 25 percentage points, representing a 314% overall increase. This increase in the likelihood of upgrading is coupled with a 76.92 kilogram increase in the quantity of fertilizer used by farmers. As a result of this increase in input use, maize yields for farmers in treated areas increased by 257 kilogram per hectare (17%). This increase in productivity is of the same magnitude as estimates by Mazur and Tetenyi (2024), who find a 25% increase in yields due to the introduction of a fertilizer ISP across 10 African countries.

Households that upgraded in 2004 were on average wealthier at baseline than both those that did not upgrade and those that upgraded by 2008. Upgrader households that remained upgraders through 2008 are substantially wealthier at baseline, more educated, larger, and hold more land. These findings are consistent with prior work that show that farmers in various African countries do not adopt improved production technologies due to credit constraints (Balboni et al., 2022), exposure to risk (Alfano and Görlach, 2024; Donovan, 2021; Karlan et al.,

[27] One could expect a short-term positive effect on out-migration, as households might reallocate liquidity towards migration in anticipation of the positive income effect of the ISP, effectively front-loading their investment in migration.

[28] Figure 5 shows the in-sample pre-trend (from the 1999-2000 season to the 2000-2001 season). Further checks (out of sample) are shown in Figure 4.

Table 1: Short- and medium-term indirect migration effects of the ISP

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	Out-migration			In-migration		Agriculture	
	HH	Individual		Individual		Upgrade	Yield
	left	any	count	any	count	binary	kg/ha
ISP (ITT estimate)	-.05	.05	.13	.01	-.01	.25	257
(2004 & 2008)	(.02)	(.02)	(.05)	(.02)	(.06)	(.01)	(146.98)
Short term	-.02	.03	.09	0	.01	.23	195.47
(2004 effect)	(.02)	(.02)	(.04)	(.02)	(.08)	(.02)	(181.12)
Med. term	-.08	.08	.18	.02	-.04	.27	328.1
(2008 effect)	(.03)	(.03)	(.09)	(.02)	(.06)	(.02)	(159.69)
N HHs	6913	6913	6913	6913	6913	6913	5371
N areas	394	394	394	394	394	394	386
Controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Pretrend pval	.54	.45	.59	.61	0	.26	0

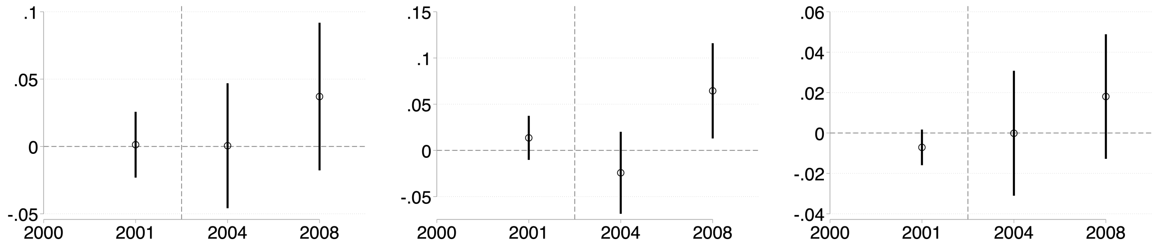
Notes: The table shows estimates for farmers treated in 2004. ISP stands for input subsidy program. Column (2) show the estimates for household out-migration moving entirely at the extensive margin, Column (3) whether the household has any out-migrants, Column (4) the number of out-migrants within households, Column (5) whether the household has any additional members, Column (6) the number of additional individuals added to the household, Column (7) is the whether the household upgraded, and finally Column (8) is the maize yield for those who planted maize (which explains the smaller sample size). For each outcome, I report the DID estimates at the area level (Equation 3). Main effects aggregate estimates from 2004 and 2008. Short-term effects are for 2004, and medium-term effects are for 2008. Standard errors (SE) are in parenthesis, and clustered at the area level. Pre-trend p-values are from the Chi-square test. Controls include baseline household size for DID.

2014) and land market frictions (Acampora et al., 2025). They are also the most likely to have out-migrants in later years (by 2008), and to have larger household sizes. These households are less likely to be headed by women. These findings are consistent with households needing to pay for the half the price of the fertilizer out of pocket (disqualifying the most credit-constrained households). See more details on the demographic breakdown of upgraders in Table A.13.

When labor markets are not fully functioning, one margin to increase labor supply, is to increase the household size by hosting in-migrants. Column (5) and (6) of Table 1 show that the ISP does not statistically increase the propensity for a household to host an in-migrant (extensive margin) or the number on in-migrants.

2.2 Results: indirect effects on migration

In what follows, I present the results on the indirect effects of the ISP on household propensity to relocate, individual propensity to out-migrate, and the number of out-migrants per household. I show that the input subsidy decreased the likelihood of a household migrating *en masse* (i.e., relocating everyone in the household). At the same time, the subsidy increased both the extensive and intensive margins of individual out-migration—the extensive margin refers to the decision of whether to migrate, while the intensive margin refers to the number of migrants per



(a) Out-migration: marriage (b) Out-migration to relatives (c) Out-migration to work

Figure 5: Difference-in-differences –Reasons to out-migrate: difference-in-differences result

Notes: This Figure plots the results from the difference-in-differences estimation from Equation 3 at the household level for the 2004 treatment cohort within treated areas using Callaway and Sant'Anna (2021). For each of the three panels, the dependent variables are given in each graph's subtitle. On Panel (a) the outcome is $Y^c_{h,t} = 1$ if the household had any out-migration due to marriages. On Panel (b) the outcome is $Y^c_{h,t} = 1$ if the household had any migrant who moved away to join relatives. On Panel (c) the outcome is $Y^c_{h,t} = 1$ if the household had any out-migration explained by work (finding work primarily). The vertical line is the year of the introduction of the subsidy. Each point estimate is the corresponding β^{2004}_t. β^{2004}_{2001} should not be statistically different from zero for the parallel trend to hold. Data are taken from the 1999-2000, 2000-2001, 2003-2004, and 2007-008 agricultural seasons. Results are shown for areas treated in 2004. Standard errors are clustered at the area level and asymptotically derived from influence functions. The vertical lines are the 95% confidence interval.

household.

I find that households are less likely to migrate *en masse*, which is consistent with the increased opportunity costs of migrating and the opportunity to benefit from the place-based transfer of the ISP. These households' best response is to stay, and, thus, households' propensity to move fell (-5 percentage points, i.e. a -28% change, see Table 1 for more details).

While households are less likely to relocate, I find that individuals are more likely to out-migrate from areas that received the subsidy either primarily to join relatives (or for income-generating activities), rather than for marriage purposes. This finding implies that the ISP triggered a diversification of income sources for households in treated areas, leading to a divestment away from agriculture. The probability that a household has at least one out-migrant increases by 5 percentage points (16%) across years (ITT; see Column (3) of Table 1). This increase in the extensive margin of individual migration is coupled with an increase in the intensive margin of individual out-migration, with an increase of .13 in the number of individuals per household who out-migrate in treated areas (whether the households received the ISP or not). Column (4) of Table 1 shows these results.

Out-migrants in 2004 were on average from households that were more educated, larger, and had more agricultural input endowments than households that had out-migrants by 2008. These differences are consistent with these households being less credit constrained than those migrating by 2008. In early ISP-treated areas, households with migrants in 2008 used the extra years to generate income to fund migration.[29]

[29] In Section A.4 of the appendix, I show averages for a range of variables for groups of households with out-migrants leaving in 2004 and out-migrants leaving in 2008, as well as households with in-migrants. I show these averages at baseline (in 2001) and at endline (in 2008). More details are available in Table A.14 of the Appendix.

2.3 Results: indirect effects on other investments

This paper examines the effects of an input subsidies on structural transformation, with a focus on agricultural and migration outcomes. However, structural transformation occurs as agriculture becomes more productive and labor reallocates away from the sector. In the analysis that follows, I estimate the effects of the ISP on investments that may signal sectoral shifts, more specifically, I estimate Equation 3 using Callaway and Sant'Anna (2021) with as right-hand side variable: education, the accumulation of productive assets (such as livestock and machinery), and business activities respectively. Table 2 presents the results.

The findings reveal an expansion in education (0.33 additional years—significant at the 10% level) for children aged 12 to 16-year-old in 2004, over the four years of the program. This expansion occurs on the year of the subsidy, likely through the relaxation of the immediate liquidity constraint in the lean season allowing farmers to keep their older children in school for marginally longer (Mukherjee et al., 2024).[30] Even if farmers remain in the agricultural sector, increased education can enhance agricultural productivity (Gille, 2020). I estimate the effects on education by restricting the sample to children aged 12 to 16 in 2004 and estimate the difference in education levels by 2008. I estimate the effects at the individual level, and I do not include children under 12 because there is limited information on them.

I also find increased investment in productive assets (1076 thousand ZKs or $269) over the four years for households in areas that receive the subsidy. These productive assets include livestock and machinery. However, the parallel trend assumption does not hold as strongly for these specific assets. By contrast, income from business activities does not differ significantly between areas that received the subsidy and those that did not.

Overall, these results suggest that farmers in areas receiving the subsidy are migrating at higher rates, investing in non-agricultural activities, while also investing in assets that increase agricultural productivity, both of which are consistent with the process of structural transformation. As a result, I find an increase in total net income, which increases by 751 (i.e. 25%), primarily in the short run.

2.4 Robustness: out-of-sample parallel trends, SUTVA, household level analysis, alternative identification.

I turn to testing the robustness of the difference-in-differences estimates. First, I present a test for the Stable Unit Treatment Values Assumption (SUTVA) using fertilizer prices and show household level treatment-on-the-treated estimates. Then, I show—using voting behavior as

[30] The ISP transfer occurs early in the lean season, while the surveys forming the panel are conducted post-harvest, when farmers are less liquidity constrained. Planting typically takes place in October/November. With additional liquidity, children are able to remain in school through the end of the school year in December. Completing the full school year, even by just a few additional months, results in a one-year increase in the last completed grade.

Table 2: Short- and medium-term effects on additional, non-migration investments

	(1) Education level	(2) Productive assets	(3) Animal sales	(4) Business income	(5) Net income (all sources)
Intent to treat	.33	1076	119	-748	751
(2004 & 2008)	(.19)	(329)	(25)	(613)	(393)
Short term	.46	576	68	-1486	779
(2004 effect)	(.3)	(331)	(19)	(1141)	(650)
Medium term	.21	1659	178	45	212
(2008 effect)	(.33)	(431)	(39)	(549)	(346)
Number HHs	668	7690	7690	5604	5604
Number of areas	314	394	394	394	394
Pretrend p-value	.52	.03	.33	.94	.54

Notes: The table shows estimates for secondary outcomes for farmers treated in 2004. Each column is an outcome, estimated using Equation 3 and Callaway and Sant'Anna (2021). Outcomes are in column (1), the education levels of households members who were aged 12 to 16 in 2004, which restrict the sample size; in column (2) is the value in thousands of Zambian Kwachas of animal and machinery assets, in column (3) the sales of live or dead animals, in column (4) gross business income, and in column (5) the net income across all sources (including fishing and retail) The ITT is the effect aggregated across the years 2004 and 2008. Standard errors are clustered at the area level and asymptotically derived from influence functions. The pre-trend p-value stems from the Chi-square test.

an instrument for receiving the ISP—that the 2SLS estimates are qualitatively similar to the ITT estimates of the difference in differences, and finally I use the Two-stage least squares to estimate an instrumented difference in differences at the area levels.

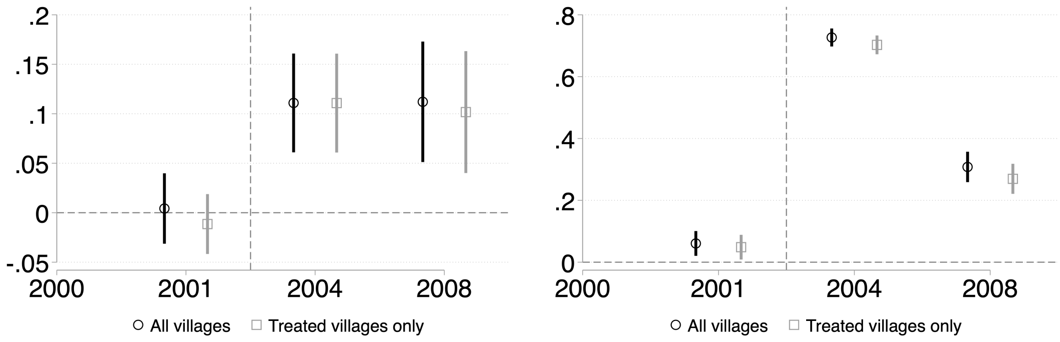
Stable unit treatment value assumption (SUTVA)

One concern with the difference-in-differences estimation is the potential violation of the Stable Unit Treatment Values Assumption (SUTVA). In the context of the Zambian ISP, such a violation could lead to spillovers across areas (the primary treatment units), impacting both migration and agricultural upgrading estimates. Specifically, if SUTVA holds we should see changes in prices within treated areas, but not across areas, which would be a threat to the identification. Because there are a handful of villages per area,[31] these areas should be large enough that spillovers should be unlikely.

To assess spillovers nevertheless, I analyze price variations of commercial fertilizer in 2004 (the year of the treatment) in provinces that have high and low treatment densities; note that these regions are larger units than areas. If there were spillovers across treatments, then fertilizer prices in provinces with a large number of treated areas would likely have been lower than those in provinces with fewer treated areas. Figure A.10 shows that fertilizer prices did not

[31] The 80$^{\text{th}}$ percentile of area size is at ten villages per area. See breakdown of the number of villages in SEAs in Table A.2)

significantly change for the "pure control" households in high-density ISP-recipient regions, which provides evidence for the SUTVA assumption.



(a) Individual out-migration

(b) Likelihood of upgrading

Figure 6: Treatment-on-the-treated estimates (household-level)

Notes: The table shows estimates for the difference-in-differences estimation at the household level within treated areas using Callaway and Sant'Anna (2021). Dependent variables are given in each graph's subtitle. Using panel data for the 1999-2000, 2000-2001, 2003-2004, and 2007-2008 agricultural seasons. Respondents' recalled information is used for the 2003-2004 and 2006-2007 seasons. The figure shows that households that received the subsidies were more likely to migrate than the households that did not receive the subsidies. Standard errors are clustered at the area level and asymptotically derived from influence functions. The vertical lines are the 95% confidence interval.

Household-level analysis

If migration primarily occurs through resale markets and price channels, the area-level effects should qualitatively mirror those from the household-level analysis. A robustness check can be performed by rerunning the analysis at the household level rather than the area level. These results estimate the average treatment on the treated (TOT). Figure 6 shows the extensive margin of individual migration (left panel) and the likelihood of upgrading (right panel). For both panels, I present the main difference-in-difference estimates from Equation 3. The treated group consists of households that received the ISP in 2004, while the control group varies: either all households that did not receive the ISP (black bars and round markers) or households in areas that received the ISP but did not participate (gray bars and square markers).

The results are consistent with the area-level difference-in-difference estimates. There is an increase in both the likelihood of a household (i) sending individual out-migrants, at a similar magnitude, and (ii) upgrading its agricultural technology at higher rates. It makes little difference whether the comparison group includes all untreated households or only those within treated areas. However, the right panel of Figure 6 shows that households that received the ISP in 2004 were more likely to upgrade their agricultural technology, even in 2001. This positive selection supports the validity of the area-level estimates. Moreover, as expected, treated households in 2004 were 70% to 80% more likely to take up the ISP than their untreated counterparts, whether in treated areas or other rural areas. This suggests that households receiving the ISP did upgrade, and this effect persisted until 2008, though it weakened, with a remaining 30% difference in the likelihood of upgrading.

Instrumenting receiving the ISP: political clientelism, and "Hausman instrument"

While the difference-in-difference estimation allows for some selection into treatment, a strong assumption for an unbiased estimation of the causal effect of the subsidy is that we are able to truly identify the areas that received the subsidy. For example, the difference-in-differences estimation may be biased if some areas had access to the subsidy but were not identified accordingly. This latter bias may be especially present if the sampling is biased (a SUTVA violation).

To address this potential bias, I use the fact that the ISP was subject to political clientelism (Mason et al., 2013, 2017), and the prices of fertilizer in neighboring areas of the district—which broadly falls under the "Hausman instruments" (Berry and Haile, 2024)—to estimate an alternative Two-stage least square strategy.[32] I find that the results from the 2SLS are qualitatively consistent with the difference-in-differences estimates in Section 2.

For election outcomes, I matched all households in the sample to constituency-level results from the presidential elections of 1996, 2001, and 2006, corresponding to the panel years 2000, 2004, and 2008, respectively. For the distance to the nearest ISP supplier, I used the distance to the provider from which households received the ISP fertilizer. For households that did not receive the subsidy but lived in areas where at least one household member did, I averaged the distance for all households that obtained fertilizer through the ISP. In areas where no household received the ISP, I imputed the distance by averaging the distances to providers from other households in the district. With that, I estimate the effects with the following model:

$$
\begin{aligned}
T_{h,t} &= \pi_0 + \pi_1 \underbrace{V_{c,t} \times dist_{h,t}}_{\text{IV: Political Clientelism}} + \pi_2 \underbrace{\frac{\sum_{j \neq i \in \mathrm{d}} Price_j}{N_d - 1}}_{\text{IV: Hausman instrument}} + \theta_1 V_{c,t} + \theta_2 dist_{h,t} + \nu_h + \eta_t + u_{h,t} \\
Y_{h,t} &= \alpha + \beta \widehat{T}_{h,t} + \nu_h + \eta_t + \epsilon_{h,t}
\end{aligned}
\tag{4}
$$

Where Y_k is alternatively extensive and intensive margin of individual out- and in-migration at the household level; $T_{h,t}$ is the endogenous variable, equal to 1 if the household received the ISP; $\frac{\sum_{j \neq i \in \mathrm{d}} Price_j}{N_d - 1}$ is the average price of the fertilizer input in the district, excluding the area (the Hausman instrument). $V_{c,t} \times dist_{h,t}$ is the political clientelism instrument, made up of the interaction of $V_{c,t}$ is a dummy variable equal to 1 if the household lives in a constituency won by the incumbent president at the previous elections and $dist_{h,t}$, the distance to closest buying point; ν_h household fixed effect; η_t time fixed effect. ν_h household fixed effect; η_t time fixed effect. Standard errors are clustered at the household level.

[32] The Hausman instrument relies on price variations for a product with a stable demand. In this context, a price change reflects changes in costs rather than shifts in demand. While this estimation could be subject to bias if the demand curve shifts, these biases are likely small. More importantly, they are orthogonal to potential biases in the difference-in-differences estimation. Thus, if the effects measured using the Hausman instrument are qualitatively similar to those from the difference-in-differences approach, this would strengthen the robustness of the results.

I estimate the effect using the variation on farmers who receive the ISP due to the voting behavior in their constituency but also due to the supplier competition and show the results in Panel A of Table 3.[33] I find an increase of 0.25 in the likelihood of having an individual out-migrant, and of .72 in the number of out-migrants. The estimates of the two-stage least square (2SLS) are larger than those of the main difference in difference for the primary fact that the estimation is at the household level,[34] and exploit the variations induced by political clientelism and the supply side conditions of the fertilizer market.

There are two ways to interpret the clientelism instrument. A first interpretation is a measure of the effort produced by the governments to reach constituents that are far away from subsidized inputs' providers. If the first stage of the 2SLS estimation yields a positive coefficient, then, we can infer that the incumbent's administration is making more efforts to reach its constituents who voted for the incumbent than its constituents who did not vote for him. An alternative interpretation of the 2SLS could be a measure of the incumbent's administration likelihood to place input providers closer to constituents who voted for the incumbent president. The first stage on Column (1) of Table 3 shows a negative (-0.003) and marginally significant coefficient on the interaction instrument, which implies that collection points tend to be placed closer to constituencies that voted for the incumbent.

Relevance conditions

I find and F statistic of 30.3 for the first stage of the two-stage least squares.

(a) Relevance of the political clientelism instrument: Mason et al. (2013) show that areas in constituencies won by the Movement for Multi-Party Democracy (MMD) at presidential receive more quantity of fertilizer at a subsidized price, i.e. fertilizers are used as a reward voting behaviors. Mason et al. (2017) find that this political impact occurs for constituency won by the incumbent, rather than gradually with the margin of the win.[35] The Buying points being the main distributor of ISP fertilizer, and a major tool for political clientelism, therefore the interaction will capture most of the existing political clientelism.

(b) Relevance of the Hausman instrument: This instrument serves as a proxy for cost shifters on the supply side. It provides an instrument for the price in the area. The idea here is that if areas within the province have specific prices, it is likely because costs in the different fertilizer markets of that province are such that prices are shifted. In this case the instrument statistically significant, and large. An increase of US$5 in the average price of fertilizer in surrounding areas of the provinces increases the likelihood of getting the ISP by 3.5 percentage

[33] See more complete version of the table in Table A.11. The local average treatment effect (LATE) interpretation of the two-stage least square is under scrutiny in recent work (Słoczyński, 2020; Blandhol et al., 2022), especially as the instruments are continuous. However, these estimates are found to estimate a causal effect.

[34] Housholds that receive the ISP should migrate at higher rates because they are the one whose credit constraint is relaxed. In fact, the 2SLS estimate are relatively close to the household level estimates of the difference in differences shown in Figure 6, with overlapping confidence intervals.

[35] In the estimation I use the data from presidential elections preceding each survey dates, the clientelism is about rewarding a vote for an incumbent.

point (only 8% of all farmers receive the ISP).

Exclusion restrictions

(a) Exclusion of the political clientelism instrument: Voting behavior and distance taken independently both could be endogenous factors influencing access to ISP through other channels. First, voting patterns may influence public goods provision, such as roads, which could affect migration beyond the ISP's impact (Burgess et al., 2015; Easterly and Ross, 1997). However, since constituencies cover broader areas than SEAs, area-level voting patterns are likely to have a limited impact on constituency-level outcomes, reducing bias. Second, proximity to the ISP fertilizer buying points may correlate with access to other agricultural programs like PAM, a smaller-scale initiative for vulnerable smallholders with less than one hectare (Chirwa and Dorward, 2013). While proximity to fertilizer providers may not directly affect migration, their location in areas with better market access could bias estimates. To address this, I control for distance to urban centers and relevant landmarks.

The interaction between distances to program's fertilizer collection points and the voting outcome should minimize most biases. Mason et al. (2013) found PAM, which may be correlated with distance to ISP fertilizer buying points, to be largely free from political manipulation. Even if non-related policies are sensitive to election results, they are unlikely to be affected by ISP buying point proximity.

(b) Exclusion of the Hausman instrument: The key identifying assumption is that commercial fertilizer prices are uncorrelated across areas, aside from transportation and exploitation costs of fertilizer suppliers, and area-specific fertilizer effects. While local demand may influence prices, for this assumption to hold, there must be limited switching of farmers between providers, ensuring that demand in neighboring markets remains distinct. This implies that prices are primarily driven by supply-side costs and area-specific characteristics. Figure A.10 in the Appendix compares prices based on the density of ISP recipients, and the results show no statistically significant variation in prices due to the number of ISP recipients. Furthermore, the first stage of the two-stage least squares regression in Table 5 demonstrates that distance to the nearest fertilizer provider significantly impacts prices, indicating that farmers face distance-related constraints.

I find results from the 2SLS presented in Column (1) of Table 3, qualitatively consistent but substantially larger than the difference-in-differences estimates. The magnitude difference is consistent with the two estimates measuring two different effects: two stage estimation measuring a 2SLS estimator rather than an intent-to-treat (ITT) as estimated by the difference-in-difference analysis.

Instrumented difference in differences

In this final robustness check, I combine the difference-in-differences (DiD) approach from Section 1.4 with a two-stage least square (2SLS) strategy to estimate an instrumented difference-in-differences (DIDIV) model. I find that the DIDIV yields results that are consistent both in sign and in magnitude. I estimated the DIDIV in three steps:

(i) In the first step, I estimate the first stage of Equation 5, where treatment in 2004 and 2008 is instrumented using (a) the interaction between distances to the program's fertilizer collection points and voting outcomes, and (b) the average fertilizer prices in nearby areas within the same district, following the Hausman instrument strategy (Berry and Haile, 2024). This estimation is done using a linear probability model.

(ii) In the second step, I rank households based on their predicted probability of receiving the ISP, and the top 10% are classified as treated, to match roughly the share of households receiving the ISP. Because the analysis is at the area level, I then assign treatment at the area so that every area with at least one household that is predicted to be treated is assigned to treatment.

(iii) Finally, I estimate Equation 6 using (Callaway and Sant'Anna, 2021) on the area-level treatment assignment derived from the IV. Specifically, I estimate:

$$T_{h,t} = \pi_0 + \pi_1 \underbrace{V_{c,t} \times dist_{h,t}}_{\text{IV: Political Clientelism}} + \pi_2 \underbrace{\frac{\sum_{j \neq i \in \mathrm{d}} Price_j}{N_d - 1}}_{\text{IV: Hausman instrument}} + \theta_1 V_{c,t} + \theta_2 dist_{h,t} + \nu_h + \eta_t + u_{h,t} \tag{5}$$

$$Y^c_{h,t} = \alpha^c + \sum_{c=2004}^{2008} \beta^c_t \widehat{\mathbb{1}}_{t \geq \widehat{c}} + \gamma_h X^{2001}_h + \epsilon_{h,t}, \tag{6}$$

Where $Y^c_{h,t}$ represents the extensive margins of migration, intensive margins of migration, and the binary decision to migrate at the household level. $T_{h,t}$ is the treatment variable, equal to 1 if the household received the ISP. The term $\frac{\sum_{j \neq i \in \mathrm{d}} Price_j}{N_d - 1}$ is the average fertilizer price in the district, excluding the area itself (the Hausman instrument). $V_{c,t} \times dist_{h,t}$ is the political clientelism instrument, which is the interaction between $V_{c,t}$, a dummy equal to 1 if the household lives in a constituency won by the incumbent president in the previous election, and $dist_{h,t}$, the distance to the nearest buying point. ν_h represents household fixed effects, and η_t represents time fixed effects. Standard errors are bootstrapped: 300 iterations of an 80% sample with replacement of the two-stage estimation process.[36] Treatment is coded as $\widehat{\mathbb{1}} t \geq \widehat{c} = 1$ if the panel year t is 2004 or 2008, where $\widehat{c}$ is the predicted treatment cohort. Specifically, $\widehat{c} = 2004$ if $P(\widehat{T}h, 2004 = 1) \geq P(\widehat{T}h, 2004 = 1)0.1$, meaning the predicted probability of treatment in 2004 (based on the first stage of the 2SLS) exceeds the 10th percentile for that year. Similarly, $\widehat{c} = 2008$ if $P(\widehat{T}h, 2008 = 1) \geq P(\widehat{T}h, 2008 = 1)_{0.1}$. Using this approach, I find that 67%

[36]This approach follows the fuzzy difference-in-differences method from De Chaisemartin and d'Haultfoeuille (2018). There could be some bias from misclassification in the first stage (Denteh and Kédagni, 2022), but the high F-statistic (30.3) in the first stage of the 2SLS suggests any bias is likely small.

of early treated areas (in the data) are predicted to be treated based on the 2SLS results.[37] I estimate Equation 5 using OLS and Equation 6 using Callaway and Sant'Anna (2021). The estimates are presented in Panel B of Table 3.

Table 3: Robustness checks: 2SLS and DIDIV

Panel A: Two-stage least square (robustness, household level)

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
	1st Stage	Out-migration			In-migration		Agriculture
	ISP	HH	Individual		Individual		Upgrade
		left	any	count	any	count	binary
ISP (2SLS)		-.02	.25	.72	.09	.29	2.89
(2004 & 2008)		(.14)	(.16)	(.39)	(.1)	(.25)	(.42)
Instruments							
MMDwon×dist.	-.0039						
	(.0027)						
Avg.(Price for Fert.)$_{-i}$	.0082						
	(.0011)						
N HHs	6922	6922	6922	6922	6922	6922	6922
F-stat	30.3						

Panel B: DIDIV using 2SLS from Panel B (robustness, area level)

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
ISP (DIDIV)		-.02	.02	.08	<0.01	-.05	.13
(2004 & 2008)		(.01)	(.03)	(.04)	(<0.01)	(.02)	(.02)
N HHs		6913	6913	6913	6913	6913	6913
Pretrend pval		.05	.98	.41	.38	.12	(<0.01)

Notes: The table shows estimates for farmers treated in 2004. ISP stands for input subsidy program. Columns (2) show the estimates for household out-migration moving entirely at the extensive margin, columns (3) whether the household has any out-migrants, columns (4) the number of out-migrants within households, columns (5) whether the household has any additional members, and finally columns (6) the number of additional individuals added to the household. For each outcome, I report the Two-stage least square (2SLS) estimates at the household level (Equation 4) in Panel A, and instrumented DID estimates (DIDIV) in Panel B (Equation 6). Main effects aggregate estimates from 2004 and 2008. Panel A instruments receipt of the ISP in 2004, and estimate the effect across years. Standard errors (SE) are in parenthesis, and clustered at the area level. The SEs for the DIDIV are obtained via bootstrap (300 iterations of an 80% sample with replacement of the first-stage regression, the classification, and the DID estimation using Callaway and Sant'Anna (2021)). Pre-trend p-values are from the Chi-square test. Controls include baseline household size, incumbent election victory and the head of household's education level, distance to closest ISP provider, and whether they voted for the incumbent party.

Although the standard errors for the instrumented difference-in-differences estimates are larger than those for the main difference-in-differences estimates due to the additional steps involved in estimation, the point estimates remain consistent across both sets of results. This holds for both the extensive and intensive margins of migration, as well as the extensive margin of upgrades. Specifically, the instrumented estimates for extensive household-level migration are -.02 compared to -.05 for the difference-in-differences estimates. For the extensive margin of individual out-migration, the estimates are .02 compared to .05, while for the intensive mar-

[37]Cross-tabulation between actual and predicted treatment is shown in Table A.12.

gin of individual out-migration, the estimates are .08 compared to .13. Lastly, for the extensive margin of upgrades, the instrumented estimates are .13 compared to .25 in the main results. In-migration, at both the extensive and intensive margins, remains statistically null, and small in magnitude across both the difference in differences and instrumented difference in differences.

3 Mechanisms: structural transformation, resale markets, and price effects

I just showed in Section 2 that the ISP in Zambia led to increases in both upgrading and migration in the areas that received the subsidy. In the following section, I explore three potential mechanisms through which the ISP may have directly driven agricultural upgrades and indirectly influenced migration: structural transformation, resale, and household specialization. Additionally, I rule out alternative mechanisms that are inconsistent with the findings. This section helps inform the assumptions underlying the model developed in Section 4.

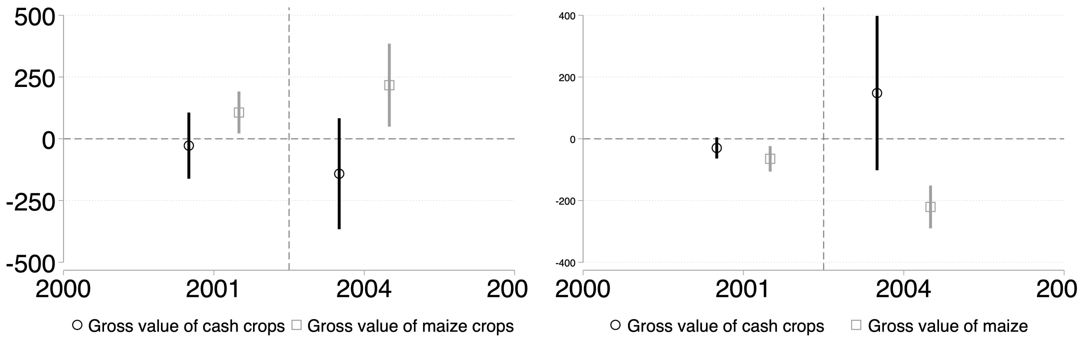
3.1 Structural transformation vs. liquidity constraints

One of the key findings in the literature on structural transformation is that various factors such as labor-saving technologies, rural overpopulation, and productivity shocks can drive people to migrate out of rural areas (Bustos et al., 2016; Lewis et al., 1954; Imbert et al., 2022). However, in contexts where households are trapped in agriculture even when migration is profitable, the distinction between labor-saving and labor-augmenting technologies may not be the primary concern. Indeed, farmers can make sequential choices that lead to increased out-migration even with labor-augmenting technologies. Specifically, they may first invest in agriculture, then use the returns from their investment to finance migration (income effects).

In Section 2, I showed the results of the intent-to-treat. The effect of the ISP on upgrading is a composite of a short-term effect (observed in 2004 for households that received the ISP in 2004) and a medium-term effect (observed in 2008 for households that received the ISP in 2004). Table 1 shows the ITT effects and disaggregates the results across short- and medium-term margins using Callaway and Sant'Anna (2021).

I find that in the short run, upgrades rates increased for all households in treated areas by 23 percentage point across all households of treated areas (see Table 1). Within four years of the introduction of the ISP, the upgrade rate rose by 27 percentage points, indicating a significant and sustained medium-term intensification of upgrades, beyond the immediate short-term effect of the ISP, which initially targeted 20% of farmers in treated areas.

The ITT effect of the ISP on the likelihood of *en masse* migration is primarily driven by households changing their migration decision in the medium run, consistent with the change in opportunity costs of migrating in 2008. Individual migration decisions in the medium-term are consistent with structural transformation. Out-migration effects in the medium run are 8 percentage points for the extensive margin (compared to 5 for the ITT) and .18 for the intensive margin (compared to .05 for the ITT). The proxy of in-migration indicates that the effects in the medium run are null.



(a) HHs with ISP (T) vs. HHs without ISP (C) (b) Has out-migrant (T) vs. does not (C)

Figure 7: Heterogeneity analysis across households on crop choice within treated areas

Notes: The table shows estimates for the difference-in-differences estimation at the household level within treated areas using Callaway and Sant'Anna (2021). Dependent variables are given in each graph's subtitle. Using panel data for the 1999-2000, 2000-2001, 2003-2004, and 2007-2008 agricultural seasons. The left panel compares incomes in US$ coming from the production of cash crops and the production of staple crops for households who specifically received the subsidy in areas that were treated, to households that did not receive the subsidy in those treated areas. On the right panel. The right panel compares households that had any number of out-migrants in 2004 (specifically), to households that had no out-migrants (in 2004) both of which are in treated areas. Standard errors are clustered at the area level and asymptotically derived from influence functions. Vertical lines are the 95% confidence interval.

3.2 Resale markets allow recipients to cash out the ISP

One mechanism that is consistent with migration occurring in the year households receive the ISP is that farmers can alleviate their liquidity constraints by participating in resale markets. Some households may choose to resell subsidized fertilizer rather than use it themselves, allowing them to finance migration or meet other immediate needs. Households that change their migration decisions in the year they receive the subsidy likely resell their subsidized fertilizer to other farmers, who can invest in agricultural technologies. This is possible because the Zambian agricultural system operates through cooperatives, where farmers receive vouchers to purchase a fixed amount of subsidized fertilizer. This system creates a market for these vouchers, providing informal channels for farmers outside the cooperatives to purchase fertilizer.

Although we lack direct data on resale markets, several pieces of compelling evidence strongly suggest their existence. For instance, The World Bank (2010) estimates that 12% of ISP recipients do not consider agriculture their primary economic activity. These households are prime candidates for reselling their vouchers since they may not use the fertilizer themselves. Additionally, self-reported data on fertilizer usage provides further support for the existence of resale markets: 3-5% of farmers in treated areas report purchasing ISP fertilizer from other households that received the subsidy, without directly receiving the voucher themselves. This is a clear indication that vouchers are being resold. Furthermore, some farmers report using much larger or smaller amounts of subsidized fertilizer than they were officially allocated, suggesting redistribution through resale markets. In fact, some households not officially listed as ISP recipients also report using ISP fertilizer, further supporting the likelihood of reallocation through resale channels (see Figures A.8 and A.8).

Table 1 shows the contribution of short-term migration decisions to the intent-to-treat (ITT) estimates. I find that households do not significantly change their decision to migrate *en masse* in the short term. However, for individual migration margins, the short-term effects—realized before any productivity gains fully materialize—contribute as much to the ITT estimates as the medium-term effects. These short-term effects imply that farmers are able to relax their credit constraints as soon as they receive the ISP, consistent with the existence of resale markets that allow vouchers to be quickly converted into cash. Specifically, the ITT estimates reveal short-term out-migration effects of 3 percentage points at the extensive margin (compared to 5 in the ITT) and 9 percentage points at the intensive margin (compared to 13 in the ITT).

I further find that areas with a high number of potential voucher resellers tend to have the highest rates of households sending out-migrants in the short term. This relationship diminishes over time, as shown in Figure A.13 in the Appendix. This trend further supports the existence of a short-term liquidity effect driven by resale markets, which enables households to fund migration soon after receiving the ISP.

To further show the plausibility of these fertilizer resale markets in the absence of direct evidence, I use data from a similar ISP for maize farmers in Mozambique, a country bordering Zambia. Using a large randomized control trial, Carter et al. (2021) estimate the long-term effects of ISPs on fertilizer adoption. A notable 30% of vouchers intended for the treatment group were ultimately redeemed by members of the control group after the original recipients chose not to redeem their vouchers.[38] This suggests that without strict adherence to the randomized control trial protocol, informal markets could have emerged, allowing ISP vouchers to be transferred from the treated farmers to the control farmers, just as we suspect occurs in Zambia. This is particularly relevant for the Zambian ISP, as it shows that vouchers can transfer outside the intended population, influencing both patterns of fertilizer take-up and general equilibrium effects examined in this study.

In another neighboring country, Malawi, which has a similar large-scale ISP, there is direct qualitative evidence of resale markets. Walls et al. (2023) documents reports of farmers selling their ISP vouchers to meet urgent liquidity needs:

> *'There are some farmers who after receiving the coupons because they are too poor... they end up selling the coupons, because the coupon is not their immediate need, their immediate need is food.'* (KII 08, District Council—Malawi)

[38] Author's calculations from Carter et al. (2021). Some farmers may not have redeemed their vouchers due to insufficient liquidity, allowing control farmers to redeem them instead.

3.3 Suggestive specialization across migration and upgrades

A final mechanism relates to correlational evidence suggesting that the households' specialization in farming or off-farm activities based on comparative advantage may lead to increases in both agricultural and migration outcomes. Following the start of the ISP in 2004, I distinguish four groups of farming households: (a) receive the ISP, (b) those who do not receive the ISP, (c) those that respond to the ISP by changing their out-migration decision, (d) those that respond to the ISP by changing their in-migration decision.

To estimate the effects of the ISP on specialization, I focus on treated areas and estimate a difference in differences across households with out-migrants, and households with no out-migrants. I examine choices made and the share of income coming from agriculture. I find that households with out-migrants divest from maize production (see Panel (b) in Figure 7) and diversify their activities by weakly investing more in cash crops (though this result has limited statistical power). By contrast, households that do not receive the subsidy, end up with some agriculture inputs, but remain more constrained than treated households, increase their cash production (though not significantly) and decrease their maize production.[39]

3.4 Assessing alternative mechanisms

There are many reasons that may lead to the increase in migration observed within areas that received the ISP. In what follows, I present alternative mechanisms and show why they are not consistent with the evidence highlighted in this paper.

Potential pricing out of non-recipients of ISPs

One possible explanation is that non-recipient households, losing competitiveness as ISP recipients become more productive due to lower input costs, may migrate more. To test this, I use a household-level difference-in-differences approach, comparing households in treated areas that received vouchers with those in treated areas that did not.

I find that farmers who didn't receive vouchers were not priced out. Instead, those who received vouchers were more likely to migrate in the short run. Households with vouchers were significantly more likely to migrate than those without, ruling out the idea that migration was driven by non-recipients being priced out of agriculture. This suggests the resale channel is more important than the pricing-out channel (Figure 6 for the household-level analysis).[40]

Additionally, the subsidy lowers input costs for voucher recipients, allowing them to fund migration through resale. This price reduction also benefits non-recipients, who see the avail-

[39] see Panel (a) in Figure 7, where a significant increase in the gross value of maize crops reflect that households that did not receive the ISP have a lower gross value of their maize. These latter results are noisy and only suggestive.

[40] Farmers who received the ISP were not only more likely to migrate but also more likely to adopt fertilizer in their agricultural technology. Figure 7 shows that treated households were much more likely to use fertilizer compared to non-treated households.

able quantity of fertilizer increase through the supply of ISP fertilizer, and who can also buy fertilizer at commercial prices in resale markets. This differs from cash-transfer programs, which tend to raise commodity prices in general equilibrium (Angelucci and De Giorgi, 2009).

Migration may occur due to an intensification of the ISP in treated areas

An alternative mechanism that can explain the long-term effects of the ISP in an area can be a succession of short-term effects in areas that received the subsidy over several years. To rule out this mechanism, I limit the 2004 sample of treated areas to areas that receive the subsidy in 2004 and not in 2006-2007 or 2007-2008. Here, I limit the control group to those never treated. By limiting the sample this way, no area in the sample receives the subsidy in subsequent years, and therefore only one effect can be observed: the effect of receiving the subsidy in one year.

Figure A.14 in the Appendix shows that the effects of the subsidy in the short run (i.e. for areas that received the ISP only in 2004) persist through 2008. Though underpowered, the analysis reveals both short- and medium-term effects of the ISP, even in areas treated only once—thus ruling out the possibility that the medium-term effects are merely a succession of short-term effects. The effects of the ISP on extensive margins are as follows: (i) for households migrating *en-masse*, -.024 percentage points in 2004 and -.028 in 2008; (ii) for households sending out-migrants, .03 percentage points in 2004 and .011 in 2008; and (iii) for households hosting in-migrants, .04 percentage points in 2004 and -.015 in 2008. These effects suggests that the medium-term effects on out-migration (both *en-masse* and individual) are a combination of successive, short-term effects and a substantial, purely medium-term effect.

4 A choice model: upgrading or migrating

The first part of this paper analyzed the expansion of a large fertilizer subsidy program to estimate how changes in liquidity and productivity impact structural transformation, measured by migration and agricultural technology upgrades. While the findings suggest that subsidies promote structural transformation, an important question remains: Are there more effective policies for enhancing both food production and productive out-migration? The remainder of the paper develops a model of choice between upgrading and migration, incorporating key features of local agricultural markets, and estimating this model to inform optimal policy design for achieving both food production improvements and migration outcomes.

This section builds on the natural experiment by examining a critical mechanism in the context: informal resale markets. These secondary markets, while not directly observable by the econometrician, are widely acknowledged as influential in shaping farmers' choices.[41] The model provides a framework for understanding these resale markets as a central driver in farmers' allocation decisions between upgrading and migration.

[41] For a detailed discussion, see Mason and Tembo (2015) and related policy reports.

The model, and later its estimation gives policy makers a tangible way to explore the trade-offs a policymaker faces when trying to design effective interventions to reduce poverty. Farmers respond to the ISP along multiple dimensions, and a simple back-of-the-envelope estimate would fail to capture these strategic behaviors. The model incorporates this complexity, allowing a more accurate analysis of farmers' responses. In the remainder of the paper, through a model and its estimation, I carefully examine these margins, as suggested by the natural experiment results. This analysis highlights the trade-offs farmers face between upgrading and migrating, allowing for a comparison of the impacts of the ISP with resale markets against other common rural policies in countries with large smallholder populations.

The setup

I model the joint decision of a single household across migration and the upgrading of its agricultural technology from a traditional to a fertilizer-based technology. The household (indexed i) behaves like a firm and maximizes its surplus across all its options. Figure 8 summarizes the joint decision considered in the model: the decision to use or not fertilizer and the decision on how many migrants to send in two environments.

Households differ in their factor endowments and have multiple labor units. Their unconstrained choices are driven by productivity differentials for a given households across technologies available in agriculture. The price of fertilizer is endogenous, influenced by whether the ISP is available in the area and the total quantity available of fertilizer available in the area. The available quantity of fertilizer is a sum of the fertilizer coming from the subsidy program and from the commercial channels, mirroring the implementation of the program in Zambia.[42] In this model, both the commercial and the ISP providers are assumed to supply a homogeneous fertilizer and there is no distinction in their quality. The model incorporates three key features: (i) farmers cannot borrow to finance migration, even when it is profitable to do so;[43] (ii) the availability of fertilizer in the area is constrained by the total commercial and subsidized quantities supplied; and (iii) resale markets allow farmers to buy and sell subdivided quantities of fertilizer in the commercial market.

Labor allocation: The household has L_i units of labor. It decides on units of labor to allocate to agriculture ($L_{i,A}$), and to migration respectively ($L_{i,M}$). $L_{i,A} \in [0, L_i]$[44] such that the household can divide an individual member's time across activities: $L_{i,A} + L_{i,M} = L_i$. Within a household, workers are homogeneous. If the household allocates any labor to agriculture, it

[42] The ISP in Zambia changed the supplied quantities of fertilizer in areas that received the program, because these ISP providers did not coordinate with commercial providers (see Section 1).

[43] In the model, I assume that fertilizer use is *not* constrained in the same way. Bryan and Morten (2019) show that there is systematic (and perhaps differential) underinvestment in migration, and that small subsidies can have substantial positive effects on out-migration.

[44] It is conceptually straightforward to add in-migration into the model, and its estimation. However, in-migration is statistically inexistent in the main estimates. For simplicity, I abstract from it in the model.

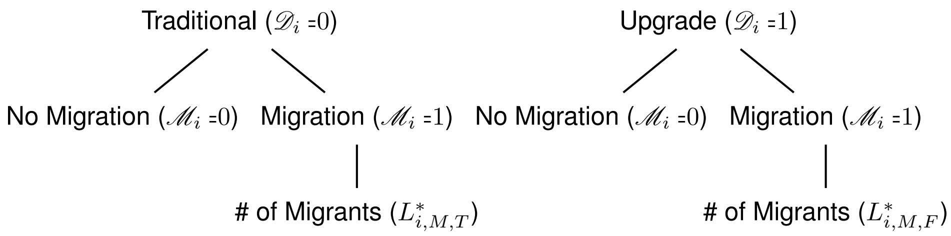


Figure 8: Household i Set of Choices in the Static Model

Notes: This figure shows the decisions a household makes in the model. In this model the household makes three joint decisions: (1) whether to upgrade its technology by using fertilizer ($\mathscr{D}_i$), (2) whether to send any migrants (binary decision $\mathscr{M}_i$), and (3) how many migrants to send.

has to choose between two technologies: (i) the traditional technology which uses labor ($L_{i,A}$) and land (X_i) as inputs, and (ii) a fertilizer technology that requires fertilizer as an additional input. Both agricultural technologies produce a homogeneous output.

Migration: The surplus generated by the labor units allocated to migration is $\pi^M = L_{i,M} \cdot \tilde{w}_i - c_i^M$, where $\tilde{w}_i = (w_i - m_v)$, with w_i being each household's member's wage at destination. The wage at destination is assumed to be normally distributed, meaning that there are heterogeneous wages at destination for different households, reflecting variations in skills and education. m_v is the marginal cost of migration; it is a function of the area in which the household lives. c_i^M is the fixed cost of migration, which can be interpreted as the initial cost that the first migrant leaving the household has to incur to find a dwelling at their destination. This cost is composed of the average cost to get to the closest city (transportation costs) c_i, and a shock j_i (which can be interpreted as the time it takes to find an income generating activity).

4.1 The household's optimization problem

Traditional agriculture: The production function for the traditional technology is $Y_i^T = a \cdot L_{i,A}^{\gamma} X_i^{\delta}$, where a is the productivity of the traditional technology (same for all households), $L_{i,A}$ the labor units allocated to agriculture, γ is the output elasticity of labor in the traditional agriculture, X_i the total available landholdings for a household i, and δ the elasticity of land. The surplus stemming from the traditional technology alone is $\pi_i^T = paL_{i,A}^{\gamma} X_i^{\delta}$.

Upgraded agriculture: The production function for the fertilizer-intensive technology is $Y_i^F = A_i \cdot L_{i,A}^{\alpha} F_i^{\beta} X_i^{1-\alpha-\beta}$, the profit function stemming from selling the production is $\pi_i^F = p \cdot A_i \cdot L_{i,A}^{\alpha} F_i^{\beta} X_i^{1-\alpha-\beta} - q_v(F_i)$, where p is the price of maize, A_i is the household's idiosyncratic productivity, F_i the total amount of fertilizer used on the farm, X_i the landholdings of the household, it is made up of the quantity received via the subsidy and the quantity traded in resale or commercial markets at a price q_v.

I make the simplifying assumption that fertilizer is subsidized at 100%, and so the household receives a quantity of fertilizer $\bar{f}$ for free.[45] When the planner introduces a fertilizer

[45] This assumption simplifies the model without affecting the estimation results. Introducing the ISP as a percentage of the prices rather than a total transfer does not significantly alter the estimation, as the maximum

subsidy (i.e. $\bar{f} > 0$) by distributing vouchers, the household can either choose to use the subsidized fertilizer in their agricultural production (i.e. $\mathscr{D}_i = 1$) or to trade its vouchers in resale markets at an endogenous area price q_v. The household uses a quantity F_i for its production where $F_i = \bar{f} + \tilde{f}_i$, where $\tilde{f}$ is the quantity of fertilizer traded in resale (or commercial markets) at a price q_v. If the household chooses to use the subsidized fertilizer, it incurs a fixed cost C_v^F associated with upgrading the technology. The cost is allowed to vary across areas to account for different specific conditions such as soil quality and whether there is a fertilizer store already set up. The household can sell its entire subsidized allocation ($\mathscr{D}_i = 0$) or buy any affordable quantity.

The commercial and resale markets for fertilizer are active, with the price q_v being the same in both. This price is influenced by the overall quantity of fertilizer available in the area.

The household faces a credit constraint: it cannot borrow against its returns to migration. This constraint implies that the household's returns from both its agricultural activity and its use of resale markets must entirely cover the fixed costs of migration. This setup allows us to see, within a static model, how farmers fund migration through both a medium-term increase in their productivity, consistent with structural change, and through a short-term increase in available cash, consistent with a relaxation of the credit constraint via resale markets. The household maximizes its total surplus by combining its returns to migration and agriculture, subject to a credit constraint. Its optimization problem is:

$$\begin{aligned}
\max_{L_{i,A,T/F}\in[0,L_i];F_i\geq 0;\mathscr{D}_i,\mathscr{M}_i\in[0,1]} & (1-\mathscr{D}_i)\left(paL_{i,A,T}^{\gamma}X_i^{\delta} - L_{i,A,T}\tilde{w}_i\right) \\
& + \mathscr{D}_i\left(pA_iL_{i,A,F}^{\alpha}F_i^{\beta}X_i^{1-\alpha-\beta} - q_v\tilde{f}_i - L_{i,A,F}\tilde{w}_i - C_v^F\right) \\
& + q_v\bar{f} + L_i\tilde{w}_i - \mathscr{M}_ic_i^M, && (7)\\
\text{s.t. } & L_i = L_{i,A} + (1-\mathscr{D}_i)L_{i,M,T} + \mathscr{D}_iL_{i,M,F}, && (8)\\
& paL_{i,A}^{\gamma}X_i^{\delta} + q_v\bar{f} \geq c_i^M \quad \text{if} \quad \mathscr{M}_{i,T} = 1, && (9)\\
& pA_iL_{i,A}^{\alpha}F_i^{\beta}X_i^{1-\alpha-\beta} - C_v^F + q_v\tilde{f}_i \geq c_i^M \quad \text{if} \mathscr{M}_{i,F} = 1, && (10)
\end{aligned}$$

where $\mathscr{D}i$ is the household's decision to upgrade its technology, taking the value of 1 if the household upgrades its agricultural technology and 0 otherwise. p is the price of maize, Ai is the household's idiosyncratic productivity, and X_i represents the household's landholdings. $\tilde{w}_i$ denotes the return to migration. $L_{i,A,T}$ and $L_{i,A,F}$ are the labor units allocated to traditional and fertilizer-based agricultural technology, respectively. q_v is the commercial/resale price of fertilizer, F_i represents the total amount of fertilizer used, $\bar{f}$ is the transfer quantity of fertilizer, and $\tilde{f}$ represents the quantities of fertilizer traded by the household (in commercial/resale markets). c_i^M and C_v^F are the fixed costs of migration and upgrading, respectively. $\mathscr{M}i, T$ repre-

likelihood estimation relies primarily on variations rather than levels, especially since input prices in the commercial market show minimal variation across locations. In practice, adding prices in the estimation would be equivalent to subtracting a lump sum equal to the out-of-pocket cost of the subsidy (i.e., 50% of the price for all ISP beneficiaries), but this ultimately does not affect the decision at the margin.

sents the extensive margin of the individual migration decision (with Li, M, T as the number of migrants) for a household using traditional agricultural methods, while $\mathscr{M}i, F$ refers to the extensive margin of the individual migration decision (with Li, M, F as the number of migrants) for a household adopting the upgraded agricultural technology. Note that $L_{i,A,T}\tilde{w}_i$ and $L_{i,A,F}\tilde{w}_i$ represent the opportunity costs of keeping labor units in agriculture rather than sending them to migrate.

The endogenous price of fertilizer in the area q_v^*

Households in an area can access both the resale market (when the ISP is available) and the commercial fertilizer market. These markets collectively determine the price of fertilizer within the area. In other words, the total transactions involving fertilizer among households should balance out to zero. This means that the sum of the fertilizer traded by every household in the area should be equal to zero. Mathematically, it means that $\sum_{i=1}^{N}\int_{w_i}\tilde{f}_i dw_i + \bar{F}_v = 0$, where $\bar{F}_v$ is the total stock of commercial fertilizer in the area. This market-clearing condition can be expressed as:

$$\overbrace{N_1\bar{f} + \bar{F}_v}^{\text{Fertilizer stock}} \quad \underbrace{- \left[\alpha^\alpha p \left(\frac{\beta}{q_v^*}\right)^{1-\alpha}\right]^{\frac{1}{1-\alpha-\beta}} \sum_{i=1}^{N^u}\int_i X_i \left(\frac{A_i}{\tilde{w}_i}\right)^{\frac{1}{1-\alpha-\beta}} dw_i - \left(\frac{p}{q_v^*}\right)^{\frac{1}{1-\beta}} \sum_{j=1}^{N^c}\left[A_j X_j^{1-\alpha-\beta}\right]^{\frac{1}{1-\beta}}}_{\text{Fertilizer traded by HHs in resale/commercial markets}} = 0 \tag{11}$$

where N_1 is the total number of households receiving the subsidy, while N^u and N^c are respectively the number of upgraders that are unconstrained (interior solution), and constrained to having all their labor in agriculture. The equilibrium price of fertilizer q_v^* has no analytical solution but can be estimated based on the number of unconstrained households N^u, the number of constrained households N^c, and the elasticities of production. Note that when $N^u = 0$, rearranging Equation 11 provides the solution for q_v^{*c}, and we have $q_v^{*c} = \frac{p}{N_1\bar{f}+\bar{F}_v} \cdot \left[\sum_{j=1}^{N^c}\int_i \left[A_j x_j^{1-\alpha-\beta}\right]^{\frac{1}{1-\beta}} dw_j\right]^{1-\beta}$, and if $N^c = 0$, rearranging Equation 11 provides the solution for q_v^{*c}, and we have $q_v^{*u} = \beta\left(\frac{\alpha^\alpha p}{N_1\bar{f}+\bar{F}_v}\right)^{\frac{1}{1-\alpha}} \cdot \left[\sum_{i=1}^{N^u}\int_i x_i \left(\frac{A_i}{\tilde{w}_i}\right)^{\frac{1}{1-\alpha-\beta}} dw_i\right]^{\frac{1-\alpha-\beta}{1-\alpha}}$. These expressions provide analytical bounds for q_v^{*u}, that depend on the weight of constrained and unconstrained households in the area.

4.2 The choice to upgrade

Unconstrained households: the interior solution

The household will upgrade to the fertilizer technology if its surplus in that technology is larger than in the traditional agriculture. In both cases, the household has the outside option of migrating. Formally, the household upgrades iff $\pi_{i,T}^{u*} < \pi_{i,F}^{u*}$, which occurs if an unconstrained household's productivity in the upgraded agriculture A_i is above a threshold. We can write:

$$\mathscr{D}_i = 1 : A_i \geq \frac{q_v^{*\beta} \tilde{w_i}^{\alpha}}{pX_i^{1-\alpha-\beta}} \left[\frac{\gamma^{\frac{1}{1-\gamma}}(1 - L_i\tilde{w_i})}{\Psi} \left(\frac{paX_i^{\delta}}{\tilde{w_i}^{\gamma}} \right)^{\frac{1}{1-\gamma}} + \frac{C_v^F + c_i^M}{\Psi} \right]^{\frac{1-\alpha-\beta}{1-\gamma}} \tag{12}$$

where $\Psi = \beta^{\frac{\beta}{1-\alpha-\beta}} \cdot \alpha^{\frac{\alpha}{1-\alpha-\beta}} - \beta^{\frac{1-\alpha}{1-\alpha-\beta}} \cdot \alpha^{\frac{\alpha}{1-\alpha-\beta}} - \beta^{\frac{\beta}{1-\alpha-\beta}} \cdot \alpha^{\frac{1-\beta}{1-\alpha-\beta}}$. And where q_v, the optimal price of fertilizer, is obtained from the market-clearing condition on the fertilizer resale market (see Equation 11). There is no closed-form solution to q_v; its expression will result from the estimation of production elasticities. A household upgrades its technology to fertilizer-intensive agriculture if, and only if, its idiosyncratic productivity (A_i) is above a given threshold. Adoption is increasing with landholding size (X_i) and maize prices (p). Specifically, for a household with a given level of productivity in fertilizer-based technology, upgrading becomes more attractive when they have larger plots to cultivate and when returns on investment are higher due to increased output prices. However, upgrading is decreasing with fertilizer prices (q_v^*), returns to out-migration ($\tilde{w_i}$), and fixed costs of upgrading and migration. In other words, when inputs necessary for upgrading are too expensive, when switching costs are high, or when the opportunity cost of remaining in agriculture is elevated (via $\tilde{w_i}$), the household must have a high level of productivity in fertilizer-intensive agriculture to justify upgrading.

For these unconstrained households, migration levels for households choosing the traditional agriculture and those choosing the upgraded agriculture are respectively:

$$L_{i,M,T}^{u*} = L_i - \left(\frac{\gamma paX_i^{\delta}}{\tilde{w_i}} \right)^{\frac{1}{1-\gamma}} \tag{13}$$

$$L_{i,M,F}^{u*} = L_i - X_i \left[\left(\frac{\beta}{q_v} \right)^{\beta} \left(\frac{\alpha}{\tilde{w_i}} \right)^{1-\beta} pA_i \right]^{\frac{1}{1-\alpha-\beta}}. \tag{14}$$

Labor constraints bind

When the household is constrained to have all its labor units involved in the agricultural technology ($L_{i,A} = L_i$), it upgrades if its productivity in the upgraded agriculture A_i is above a threshold. We can write:

$$\pi_{i,F}^{c*} \geq \pi_{i,T}^{c*} \tag{15}$$

$$A_i \geq \left[\frac{paX^{\delta} + C_v^F}{\beta^{\frac{1}{1-\beta}} - \beta^{\frac{1}{1-\beta}}} \right]^{1-\beta} \frac{q_v^*}{pX_i^{1-\alpha-\beta}} \tag{16}$$

For these constrained households, migration levels are $L_{i,M,T}^{c*} = L_{i,M,F}^{c*} = 0$ regardless of the agricultural technology they choose.

Testing the implications of the model

Implication 1—There are four groups of households: (i) households that upgrade, and do not have out-migrants; (ii) households that upgrade, and have out-migrants; (iii) households that do not upgrade and do not have out-migrants; (iv) households that do not upgrade, and have out-migrants.[46]

Implication 2—Households delay their migration decision, to use the income from their agricultural upgrade to fund migration.[47]

Implication 3: Migration increases as the resale value of the subsidized fertilizer increases. As the resale value of the vouchers increases, migration becomes comparatively more attractive. This correlation results from the credit constraint being relaxed for more households. Additionally, it also implies that the opportunity cost of the marginal hectare of fertilizer agriculture is higher because it becomes too costly to top-up, and migration becomes relatively more attractive. The correlation between the resale price (which I proxy by using the commercial price) and individual migration at the extensive margin is 0.07 in 2004 and 0.08 in 2008.[48] Furthermore, for each additional US$1 of subsidy, there is a 0.2 percentage point increase in the likelihood that a household sends at least one member out and a .1 percentage point increase in the number of people sent out (for regression results, see Table A.16 and Figure A.11).

5 Estimation, in-kind and cash counterfactuals

In this section, I estimate the model of selection presented in Section 4 by Maximum Likelihood; I then use the parameters from the baseline model (ISP with resale) to back out the parameters of the model and estimate the following counterfactual policies: (i) an ISP without resale markets, similar to an in-kind transfer, (ii) a cash-transfer program, with the same pecuniary value as the subsidy for the same households that previously received the ISP, (iii) a smaller cash transfer to all households within treated areas.

5.1 Estimating the model of selection

The benchmark estimation: the ISP and migration

I estimate the baseline ISP parameters in three steps: (i) I estimate the production functions for both the traditional (non-upgraders) and upgraded agricultural technologies. (ii) Using the results from the first step, I compute the counterfactual outcomes of upgrading for non-upgraders and of staying in traditional agriculture for upgraders. Additionally, I predict the amount of fertilizer non-upgraders would have used had they upgraded. This step allows me to estimate the output in the upgraded technology, Y_i^F, for non-upgraders and, in turn, infer productivity in upgraded agriculture for both upgraders and non-upgraders. (iii) Finally, I estimate the joint household decisions to upgrade and migrate. Standard errors are in parenthesis are boot-

[46]For corresponding propositions, see propositions 1, 2, and 4 in Appendix B.

[47]For corresponding propositions, see Proposition 3 in Appendix B.

[48]Figures A.12 and A.11 in the Appendix plot these correlations.

strapped: 300 iterations of an 80% sample with replacement of all steps of the estimations.

Production functions:

The optimal levels of migration depend on elasticities and prices. As a first step, I estimate the Cobb-Douglas production functions from Section 4. I do not instrument the inputs of the production function (Olley and Pakes, 1992) because land inputs are fixed, and labor markets are incomplete (Rosenzweig, 1988).

I estimate the production functions for each technology pooling all four waves of the panel (1999-2000, 2000-2001, 2003-2004, and 2007-2008). For the fertilizer intensive technology, I estimate the function among adopting farms (i.e. farms that reported using fertilizer) and compute the counterfactual production for non-adopters. This identification accounts for the inputs of the production function and the area fixed effect, which is the deterministic component of A_i. The residual of $\log(\nu_i)$ is the idiosyncratic part of A_i. The estimation (see Table 4) shows that the fertilizer technology has an increasing return to scale. While the traditional technology has a constant return to scale.

Table 4: Estimation of the production functions for agricultural technologies

(A) Fertilizer: $\log(Y_{maize,i}) = \log(A_i) + \alpha\log(L_{i,A}) + \beta\log(F_i) + \nu\log(X_i) + \theta_{vil}$

Sample: ISP + Adoption	α	ν	β	$\alpha+\nu+\beta$	P-value $H_0: \alpha+\nu+\beta=1$
Estimates	.116	.736	.306	1.158	.00
Standard Errors	(.037)	(.037)	(.029)		

(B) Traditional: $\log(Y_{maize,i}) = \gamma\log(L_{i,A}) + \mu\log(X_i) + \theta_{vil}$

Sample: ISP + No adoption	γ	μ		$\gamma+\mu$	P-value $H_0: \gamma+\mu=1$
Estimates	.133	.828		.961	0.26
Standard Errors	(.030)	(.028)			

Notes: This table shows the estimates for the Cobb Douglas equations on Panel (A) for the Fertilizer technology and Panel (B) for the Traditional technology. Standard errors are clustered at the area level. P-value are for the test of constant return to scale.

Fertilizer use, and output:

I only observe the total quantity of fertilizer used (F_i) and production of maize in the fertilizer agriculture (Y_i^F) for upgraders, and Y_i^T for non-upgraders. To estimate their corresponding $\widehat{Y_i^T}$ for upgraders and $\widehat{Y_i^F}$ for non-upgraders, I focus on the year 2004, which is the year for which I estimate the joint decision to upgrade and migrate. I estimate $F_{i,2004}$ as such:

$$F_{i,2004} = a_0 + a_1\text{Production Value}_{2001} + a_2\text{Fallow land}_{2001} + \text{FE}_v + e_i, \quad (17)$$

where $F_{i,2004}$ is the quantity of fertilizer households used in 2004, based on their baseline production value — a proxy for their crop and quantity choices — and the size of their fallow land (land uncultivated in 2001), which serves as a proxy for their production growth potential. I also control for area fixed effects to account for variations in fertilizer efficacy across areas.

Once I estimate total quantity of fertilizer used (F_i) among upgraders, I compute $\widehat{F_i}$ for the non-upgraders. Using $\widehat{F_i}$, I compute $\widehat{Y_i^F}$ for non-upgraders, and, thus, back out the household level productivity that stems from upgraded agriculture (A_i). To estimate $\widehat{Y_i^T}$, I use household landholdings, and the total labor units available to the households L_i as inputs.

Joint decision to upgrade and to migrate:

To estimate the binary decision to upgrade, the decision to have migrants, and the number of migrants, I estimate simultaneously three equations with three left-hand side variables: the binary decision to upgrade $\mathscr{D}_i$, the binary decision to migrate $\mathscr{M}_i$, and number of migrants L_{iM}). To identify the parameters, I estimate Equations 18 and 19 using simultaneous maximum likelihood using the variation generated by the ISP.

Joint decision in areas without the ISP:

$$\begin{cases} \mathscr{D}_i & = \alpha_0 \log(X_i) + \alpha_1 \log(q_v) + \alpha_2 \log(A_i) + \alpha_3 \log(c_i) + FE_v + \epsilon_i \\ \mathscr{M}_i & = \beta_0 + \beta_1 L_{iM} + \beta_2 Y_{i,T} + \beta_3 \mathscr{D}_i (Y_{i,F} - Y_{i,T}) + \beta_4 q_v + \beta_5 c_i + \mu_i \\ L_{iM} & = \gamma_0 \mathscr{D}_i \log(A_i) + \gamma_1 \log(X_i) + \gamma_2 \log(c_i) + \gamma_3 \log(P_v) + \gamma_3 \log(L_i) \\ & \quad + \gamma_4 \mathbb{1}_{\text{fsp}} \times \log(q_v) + \gamma_5 \log(q_v) + \theta_i \end{cases} \tag{18}$$

Joint decision in areas with the ISP:

$$\begin{cases} \mathscr{D}_i & = \alpha_0 \log(X_i) + \alpha_1 \log(q_v) + \alpha_2 \log(A_i) + \alpha_3 \log(c_i) + FE_v + +\epsilon_i \\ \mathscr{M}_i & = \beta_0 + \beta_1 L_{iM} + \beta_2 Y_{i,T} + \beta_3 \mathscr{D}_i (Y_{i,F} - Y_{i,T}) + \beta_4 q_v + \beta_5 c_i + \mu_i \\ L_{iM} & = \gamma_0 \mathscr{D}_i \log(A_i) + \gamma_1 \log(X_i) + \gamma_2 \log(c_i) + \gamma_3 \log(P_v) + \gamma_3 \log(L_i) \\ & \quad + \gamma_4 \mathbb{1}_{\text{fsp}} \times \log(q_v) + \gamma_5 \log(q_v) + \underbrace{\gamma_6 \mathbb{1}_{h,ISP} \times q_v}_{\text{Resale returns: ISP HHs}} \quad \theta_i \end{cases} \tag{19}$$

Identification of Equation 18: I use the fact that some areas have access to the ISP and others do not, and the fact that within treated areas, some households receive the ISP and others do not. The estimation for ISP-recipient areas allows me to estimate the decisions stemming from equations 12, 10, and 14. While the households receiving the ISP allow me to estimate the resale markets. More specifically $\mathbb{1}_{h,ISP} \times q_v$ is the effect of the price of the fertilizer for households that receives the ISP within treated areas. The latter estimates the equilibrium effects of the resale price on household migration decisions.

Each of the parameters used in the estimation is constructed using the description from Table C.1. Table 5 summarizes the mean and standard deviations of upgrading ($\mathscr{D}_i$), migrating ($\mathscr{M}_i$), and labor units migrating (L_{iM}) for 10% of the hold-out sample. Overall, the out-of-sample estimates (see Column 3 of Table 5) approximates well the moments of the data (see Column 2 of Table 5). The out-of-sample difference between the estimates and the actual value $\mathscr{M}_i$, L_{iM} are respectively .1% and 5%, while $\mathscr{D}_i$ is at -23%.

Estimating revenue in agriculture: I compute $p \cdot Y_i^T$ and $p \cdot \widehat{Y_i^F}$ for non-upgraders and $p \cdot Y_i^F$ and $p \cdot \widehat{Y_i^T}$ for upgraders.

Table 5: Out-of-sample fit of the model

(1) Variable	(2) Statistics	(3) Estimates	(4) Actual	(5) Difference
$\mathscr{D}_i$	Mean	.762	.617	-.145 (-23.5%)
	SD	.427	.487	
$\mathscr{M}_i$	Mean	.606	.610	.004 (+0.1%)
	SD	.490	.489	
L_{iM}	Mean	1.933	1.851	-.082 (+4.3%)
	SD	1.398	2.238	

Notes: This table shows the estimated moments of household's decisions. $\mathscr{D}_i$ is one HH's decision to start using fertilizer (upgrade). $\mathscr{M}_i$ is one HH's decision to send units of labor to out-migrate. L_{iM} is the optimal number of labor units the HH sends to out-migrate. Column (2) shows the statistics displayed (mean, and standard deviation). Column (3) is the fitted estimate from Equation 18 for the 10% out-of-sample households. Column (4) is the actual value of each of the variables (and statistics). Column (5) is the out-of-sample percentage of error between the estimate and the actual value (i.e., Column (4) - Column (3) and in parenthesis it is $\frac{Column(4)-Column(3)}{Column(3)}$.

5.2 Counterfactual policies: subsidies vs. transfer programs

Using the estimates obtained baseline policy in the model, I estimate the counterfactuals for several popular, rural anti-poverty policies. First, under the model assumptions I explore what would happen with an enforced ban on resale markets and two cash- transfer programs (a targeted and universal basic income).

ISP without resale: Shutting down the resale markets impacts the reallocation of fertilizer in the local market. Furthermore, farmers with a comparative advantage in migrating cannot generate liquidity to fund migration. This scenario results in substantial efficiency losses, with a decrease in both upgrading (-64.54%) and migration (-4.71%). In this case, the improvement in overall productivity is negative compared to the ISP with resale markets. Indeed, the ISP with resale markets directly generates more upgraders than beneficiaries because farmers can split their fertilizer transfer across several households.

I test two ways of designing the cash-transfer policy. First, I use the targeting of the ISP and provide a revenue neutral cash transfer to farming households that had previously received the subsidy. I use a narrow definition of revenue neutrality that equalizes the cash transfer to the dollar amount of the fertilizer transfer under the ISP, this definition does not account for operational costs of running either the cash transfer or the subsidy programs. In a second design of the revenue-neutral cash-transfer program, there is no targeting; all farmers living in a treated area receive some amount of cash, but they receive smaller quantities than would be the case in the targeted counterfactual.

Cash transfer programs: The cash-transfer programs have two main feature differences with the baseline ISP with resale. First, the cost of transportation c_i goes down by the amount of the cash transfer. This drop in costs impacts both the decision to upgrade the household's agricultural technology $\mathscr{D}_i$ and its decision to migrate $\mathscr{M}_i$. For households with low transportation costs, the leftover cash is added to the total revenue. Second, the price of fertilizer increases as the total amount of fertilizer available in the area decreases. This is because the central planner no longer provides the subsidized quantity of fertilizer. To estimate the costs of fertilizer, I use Equation 11, and estimate the following:

Equilibrium fertilizer price q_v^*:

$$log(q_v) = \beta_0 + \beta_1(N_{1v}\bar{f} + F_v) + \beta_2 N_{1v} + \beta_3 N_v^u + \beta_4 N_v^c + \epsilon_v,$$

where $N_{1v}\bar{f}$, is the number of households in the area that receive the subsidy. N_v^u is approximated by the number of households that have migrants and N_v^c by the total number of households net of the constrained households.

Targeted cash transfer: The targeted cash-transfer program decreases both migration rates (-5.32%) and the adoption of the fertilizer technology (-70.87%) compared to the baseline of ISP with resale markets. First, the market frictions in technology upgrades are not internalized, and adoption rates plummet compared to the ISP with resale markets. Second, migration also decreases because, unlike the baseline ISP, the cash is fungible, and there is no redistribution of the cash across households. In this case, only the households receiving the subsidy can change their migration decisions. Another aspect of the model is that households that upgrade and generate profits with the fertilizer technology can fund migration. Because the targeted cash transfer leads to no adoption, there are no spillover effects through prices.[49]

Universal basic income: The transfer is a one-off universal cash-transfer program decreases migration rates (-5.32%) compared to the rates the ensue under the ISP with resale markets; at the same time the universal basic income program has strong negative effects on the adoption of the fertilizer technology (-79.87%). This effect is because the market frictions in the fertilizer market remain. [50] Panel A of Table 6 summarizes the counterfactual estimates.

5.3 Discussion: first best and second-best policies

First-best policy

Considering both the credit constraint and the market frictions in the economy, a first-best policy to minimize distortions and improve the efficiency of the policy would be to identify the

[49] I re-compute the counterfactual keeping the available fertilizer quantities at the level of the ISP currently in Zambia. I find drops in upgrades rates (-65.33%), in migration rates (-4.48%) but an increase in the total number of migrants (11.01%).

[50] I re-compute the counterfactual but I keep the available fertilizer quantities at the level of the ISP currently in Zambia. I find drops in upgrades rates (-75.43%), in migration rates (-4.48%) but an increase in the total number of migrants (-5.78%).

Table 6: Summary of counterfactual policies

Panel A: Structural estimates for upgrades and migration

	Channels	Upgrade extensive	Migration extensive	Migration intensive
Baseline:				
- ISP + resale	Upgrade: resale, fertilizer prices			
	fertilizer quantities	.664	.663	1.84
	Migration: resale, productivity	(0.015)	(0.016)	(0.044)
Counterfactuals:				
- ISP no resale	Upgrade: fertilizer prices			
	fertilizer quantities	.276	.640	1.83
	Migration: productivity	(0.097)	(0.032)	(0.06)
- Targeted CT	Upgrade: lower transport costs	.227	.636	2.05
	Migration: lower transport costs	(0.448)	(0.04)	(0.53)
- Universal CT	Upgrade: lower transport costs	.157	.636	1.74
	Migration: lower transport costs	(0.445)	(0.04)	(0.52)

Panel B: Back-of-the-envelope effects on income

	Input subsidy		Cash transfers	
	Baseline: resale	No resale	Targeted	Universal
Mean revenue$^{(*)}$	\$698	\$566	\$961	\$653
Median revenue$^{(*)}$	\$315	\$253	\$344	\$257

Notes: This table shows the estimates of the model using Maximum Likelihood. The extensive margins of upgrading and migrating are obtained splitting the probability into a binary variable that equals 1 if the estimated probability is greater or equal to 0.5, and 0 otherwise. Standard errors are in parenthesis are bootstrapped: 300 iterations of an 80% sample with replacement of all steps of the estimations.
$(^{*})$ Mean and median revenue include returns from agriculture as well as the lump sum for the cash transfer.

two types of farmers—those who would be better off migrating and those who would be better off upgrading—and then lifting the corresponding constraints of farmers in each group. Farmers that have high productivity in the fertilizer-based technology could see their constraints lifted via the ISP, which would address affordability and increase available quantities of fertilizer. Conversely, farmers "trapped" in agriculture—that is, who would be better divesting from agriculture—could receive a cash transfer to address the financial frictions preventing their relocation. Such a policy relies on the central planner's ability to observe farmer types for which elicitation is costly.

Second-best policies

ISP with resale markets (estimated policy in Zambia): Resale markets for fertilizers enhance allocative efficiency by reallocating fertilizer toward farmers in greater need, while generating income for the net sellers. The amount of fertilizer can be split across farmers, creating a snowball effect. However, this policy may introduce distortions (Diamond and Mirrlees, 1971; Mirrlees, 1986). When resale transaction costs are low, this second-best policy approximates the first-best policy in a decentralized manner. The adequacy of the subsidy hinges on the trade-off between a price distortion-induced efficiency loss, increased technology upgrade, and redistribution components.

ISP without resale markets: Without resale markets, the price effect benefits only ISP recipients. Meanwhile, farmers' ability to relax their credit constraint is reduced and farmers can only increase their migration by increasing their productivity in the medium term. Furthermore, unless the planner can elicit types and only provide the subsidy to farmers with the highest returns to upgrading, this policy would introduce a deadweight loss from the inability of farmers to efficiently distribute the subsidized fertilizer. This deadweight loss can be lowered if the cost of eliciting farmer types is low. Alternatively, the central planner could encourage and remove the frictions in resale markets.

Targeted cash transfer: The cash-transfer program given only to the recipients of the ISP in 2004 improves migration outcomes but only in the short run. The channel of increased income from upgrading is reduced for recipients. With this cash-transfer program, the multiplier effect of the subsidy disappears. However, with various estimates of the returns to a cash-transfer program, it may be a better alternative for poverty reduction—but only for the 8% who receive the transfer. Farmers that receive the cash transfer can fund migration, but farmers who do not experience unaltered outcomes. Unlike the ISP with resale markets, the policy's returns do not spill over to the other farmers (i.e. there is no snowball effect). Market frictions remain, and upgrade rates plummet.

Universal basic income: This cash-transfer program is given to all farmers residing in targeted areas. It relaxes the credit constraint for a larger number of households, which can then migrate. However, like the targeted cash transfer, upgrade rates are very low as a result of the transfer.

Optimal policy

If the central planner has a dual objective of moving farmers from a low to a high fertilizer adoption equilibrium while also redistributing income to those facing financial constraints, then resale markets could be an improvement over the no-subsidy alternative. In the Zambian agricultural system, a limited ISP randomly provided to farmers could lead to efficiency gains (Giné et al., 2022) and a rise in both adoption and migration rates. Carter et al. (2021) find that temporary subsidies can lead to long-lasting effects on adoption by moving farmers to a better fertilizer-use equilibrium. Based on their findings, an optimal policy may involve introducing the ISP with resale markets and phasing out the subsidy once a critical mass of farmers upgrades their agricultural technology and starts using fertilizer. The ISP can then be phased out and replaced by a universal basic income (or universal cash-transfer) program. This optimal policy does not require the central planner to elicit farmers types and saves costly targeting expenses. Instead, the central planner can encourage resale markets and remove frictions that may lower the efficiency of these markets. In neighboring Malawi, Boone et al. (2013) show that combining cash transfers with ISPs can have a multiplicative impact of improving fertilizer adoption, increase farm production and further relax the credit constraint for individuals living in extreme poverty.

Conclusion

I examine the effects of a large-scale Zambian input subsidy program (ISP) on farmers' investment choices by focusing on agricultural upgrading (fertilizer use) and out-migration. Using the staggered rollout of the ISP as a natural experiment, I estimate a difference in differences and find that the ISP significantly increased both upgrade and out-migration rates. Building on these findings, I develop a static choice model to generalize the observed behaviors. The model incorporates key features, including resale markets for the subsidized fertilizer (with endogenous fertilizer prices), a credit constraint (that is relaxed by the ISP). I estimate the model and compare the current ISP with resale markets to three revenue-neutral, counterfactual policies.

The findings suggest that an ISP can simultaneously address the market frictions affecting both the adoption of fertilizer in agriculture and credit constraints. Alleviating credit constraints allows for the sorting of farmers based on comparative advantage, while the potential allocative inefficiency of subsidies is partially offset by the existence of resale markets.

The empirical part of this paper leverages a unique setting to examine the impact of an input subsidy on a variety of household decisions, also has limitations. First, I do not observe the destination of out-migrants or the origin of in-migrants, which limits the extent to which I can infer the changes in welfare for beneficiary households. I also do not directly observe resale markets, which implies a loss in precision regarding the demand for fertilizer within local areas. A third limitation stems from the frequency of data collection, which occurs every four years and does not allow me to distinguish between seasonal and long-term migration. Future work can explore the dynamic effects of these policies. Although migration decisions are not the sole objective of these policies, this paper is a first step in exploring the indirect impacts that policies might have on migration patterns over time and within countries. The findings can provide information to policymakers when deciding on the allocation of resources.

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A Appendix

A.1 Some context on rural antipoverty programs

A.2 Data and descriptives

First, Census Supervisory Areas (CSAs) were chosen within each district. Second, Standard Enumeration Areas (SEAs) were sampled from each CSA, and finally, households within each SEA were randomly chosen to be interviewed. In addition to the household surveys conducted in 2000, 2001, 2004, and 2008, the 2008 survey includes community-level information gathered from the community headman. This dataset provides information on basic features of communities, rules, constituencies, and distances to main provincial landmarks.

Table A.1: Number of administrative units in the sample

	2000	2001	2004	2008
Provinces	8	8	8	8
Districts	37	37	37	37
Census Supervisory Areas (CSA)	112	112	112	112
Standard Enumeration Areas (SEA)	394	394	394	394
Households	7,859	7,699	6,922	9,347
Communities				1,053

Notes: This table plots the sampling across years for the 1999/2000 Post Harvest Survey and its supplementary surveys.

Table A.2: Size of Standard Enumeration Areas (SEAs), measured by the number of villages

(1) # villages in SEA	(2) Number of SEAs	(3) Percentage of SEA %
1	11	3%
2	10	3%
3	29	7%
4	27	7%
5	48	12%
6	43	11%
7	43	11%
8	38	10%
9	29	7%
10	34	9%
11	26	7%
12	12	3%
13	13	3%
14	18	5%
15	5	1%
16	3	1%
17	5	1%
Total	394	100%

Notes: This table provides a breakdown of the Standard Enumeration Areas (SEAs) based on the number of villages they contain. Although each SEA is sampled to represent the same population, the number of villages may vary. Column (1) lists the number of villages in each SEA, Column (2) shows how many SEAs have that specific number of villages, and Column (3) indicates the percentage of SEAs with that number of villages.

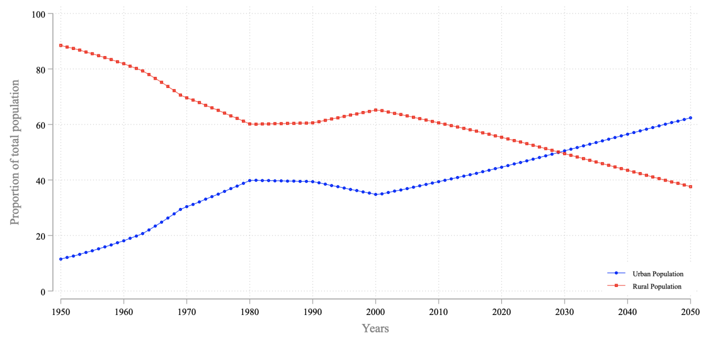


Figure A.1: Rural and Urban Population in Zambia (with projections)

Notes: This figure plots the evolution over time of both the urban and rural populations over the years. Source: United Nations, World Urbanization Prospects: The 2018 Revision.

Table A.3: Household receiving ISP

		2001		2004		2008	
		Total	Percent	Total	% Population	Total	% Population
Total ISP hh		0	0	496	7.17%	525	9.02%
		2001		2004		2008	
		Total	Percent	Total	% ISP subset	Total	% ISP subset
Received ISP	has out-migrant	0	0	226	46.56%	328	62.48%
	no out-migrants	0	0	270	54.44%	197	37.52%
	has in-migrant	0	0	131	26.41%	165	31.43%
	no in-migrants	0	0	365	73.59%	360	68.57%

Notes: This table shows the count and shares of households that receive the ISP among those who have out-migrants, and those who have in-migrants. The sample is all households who received the ISP at any point in the panel (either in 2004 or in 2008). For example: 226 households who had out-migrants in 2004 also received the ISP, and 270 had out-migrants in 2004 and did not receive the ISP. and the rates are contemporaneous. and whether they di Author's calculations using the Supplemental Survey to the 1999/2000 Post Harvest Survey - Zambia Data Documentation, revised June 2010.

Table A.4: Characteristics of households in the panel

Panel A: Panel Classification of households	Frequency	Percent
Household is found in 2001,04,08	4,288	61.9
Household is found in 2001 only	1,273	18.4
Household is found in 2001 & 2004 only	1,070	15.15
Household is found in 2004 & 2008 only	52	0.8
Household is found in 2000 & 2008 only	230	3.3
Household is not found*	9	0.1
Household is found in 2000 only	777	-
Total number of households	7,699	-

* The household was interviewed in 2004 or 2008 but was not the same as the one interviewed in 2001

Panel B: household survey response status			
B.1 Non-migrant households	2001	2004	2008
Completed	6,922	5,419	4,301
Skipped & not interviewed	0	30	0
Currently away from home	0	0	55
Non-contact	337	362	0
Refusal	3	14	22
Dissolved	85	390	366
B.2 Migrant households	2001	2004	2008
Completed after moving to another area	0	0	269
Moved out of area	352	707	810
Total number of households	7,699	6,922	5,823

Notes: This table details the sample of households. Panel A shows when households are found in the panel, and Panel B displays the response statuses of households for each follow-up year. Panel B.2, are the households I define as migrant households.

Table A.5: Individuals' reason to out-migrate (Panel A) and in-migrate (Panel B)

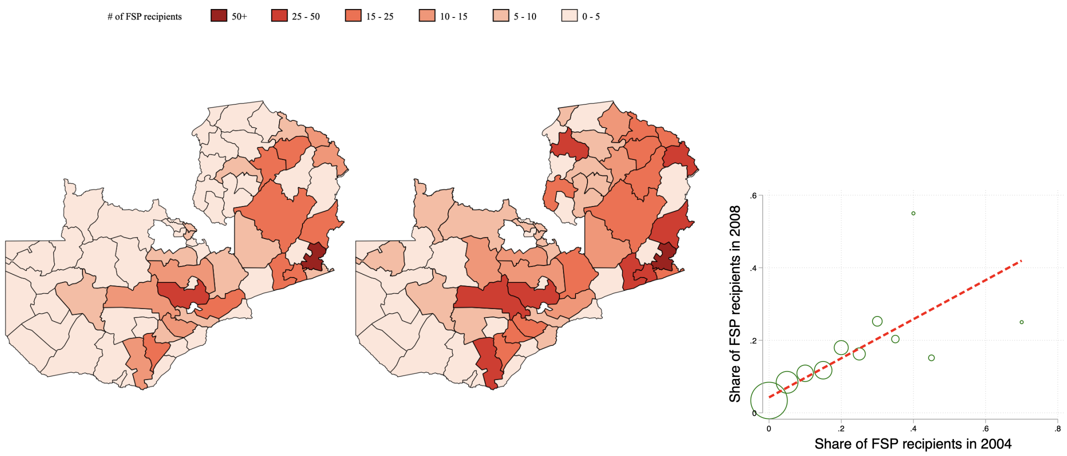
Panel A: Household's members reason for out-migration

(1) Reasons for out-migration	(2) Share in 2004	(3) Share in 2008	(4) Classified
Married Away	40%	27%	Out-migrant
Living With Other Relatives	23%	17%	Out-migrant
Left To Find A Job	10%	6%	Out-migrant
Divorced	4%	2%	Out-migrant
Separated	2%	1%	Out-migrant
Not Given	1%	4%	Out-migrant
Established Own Home	1%	3%	Out-migrant
Other (Specify)	0%	24%	Out-migrant
Deceased	14%	11%	Not an out-migrant
Never A Member / Not Known	4%	5%	Not an out-migrant
Total count of individual out-migrants	4,581	5,978	

Panel B: Household's members reason for in-migration

(1) Reasons for in-migration	(2) Share in 2004	(3) Share in 2008	(4) Classified
Returned To Help With Activities	32%	11%	In-migrant
Married Into The Family	24%	22%	In-migrant
Lost Parents	20%	16%	In-migrant
Fostered	6%	5%	In-migrant
Other (Specify)	5%	9%	In-migrant
Returned To HH Because He/She Is Sick	4%	1%	In-migrant
To Go To School	2%	3%	In-migrant
Widowed	2%	9%	In-migrant
Divorced	2%	13%	In-migrant
Needed Help, Not Sick	1%	0%	In-migrant
Followed The Parent	1%	0%	In-migrant
Old Age, To Be Cared For	1%	1%	In-migrant
Worker For the household	0%	9%	In-migrant
Total count of individual in-migrants	1,688	1,817	

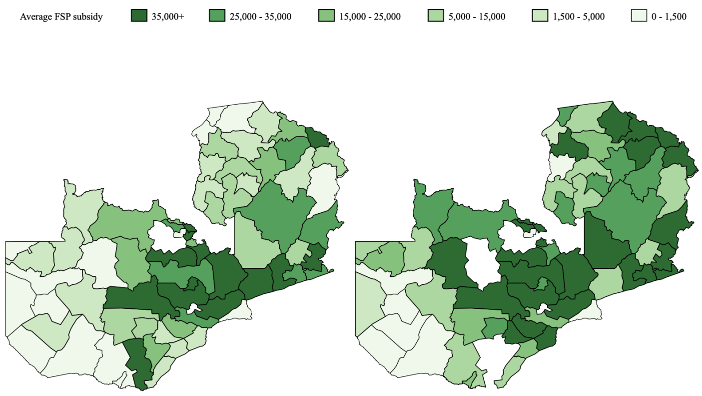
Notes: This table breaks down the reasons why household members migrated in 2004 and in 2008. The sample is all households in the panel dataset. Panel A of the table shows the reasons why households sent out-migrants, and Panel B shows the reasons why households hosted in-migrants. Column (1) is the listed reason why, Column (2) and Column (3) is the share of the total listed migrants who left or joined, for each of these reasons by 2004 and 2008 respectively, and Column (4) lists whether that reason is classified as migration or not. The last row of each table provides the total count of migrants in 2004, and in 2008 (excluding 2004 migrants). Out-migrants outnumber in-migrants almost in a ratio of 3:1.



2004 | 2008 | Correlation between the share of recipients (in an SEA) in 2004 and 2008

Figure A.2: Maps of ISP recipients per districts in 2004 and 2008

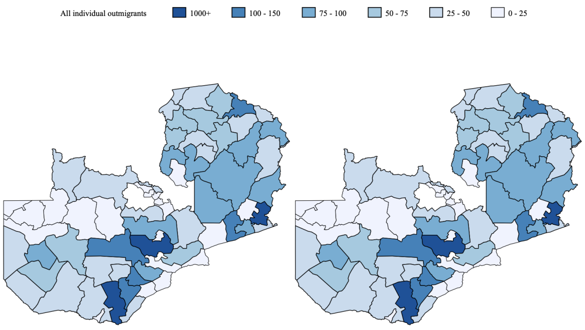
Notes: This figure presents two maps of the distribution of ISP recipients in the country in 2004 and in 2008, and a scatter plot of the correlation receiving the ISP in 2004 (x-axis of the plot on the right) and receiving the ISP in 2008 (y-axis). The sample is all ISP recipients. The shape files used correspond the time period of the study, though there have since been changes in districting since 2011.



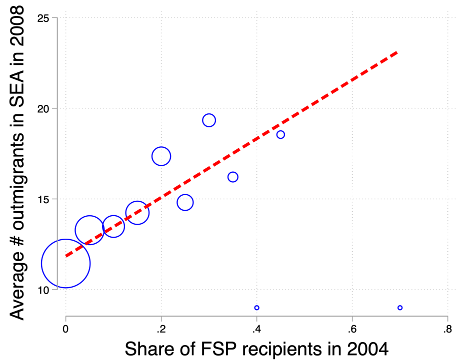
2004 | 2008

Figure A.3: Average amount (ISP) disbursed per household in 2004 and 2008 - by district

Notes: This figure presents two maps of the distribution of ISP amounts across provinces of Zambia in the country in 2004 and in 2008. The ISP amounts are measured by the multiplying the size of the subsidy (50% and 60%) by the price in the province. The sample is all provinces. The shape files used correspond the time period of the study, though there have since been changes in districting since 2011.



2004 2008



Average count of out-migrants in SEA in 2008 vs. Share of ISP recipients in 2004

Figure A.4: Maps of the number of individual out-migrants in 2004 and 2008 - Per district
Notes: This figure presents two maps of the distribution of out-migrants in Zambia in the years 2004 and in 2008, and a scatter plot of the correlation between the share of ISP recipients in 2004 (x-axis of the plot on the right) and the number of migrants in 2008 (y-axis). The sample is all areas in the panel. The shape files used correspond the time period of the study, though there have since been changes in districting since 2011.

A.2.1 More details on the context of the Zambian ISP

Until 2001, a loan program called the *Fertilizer Credit Program* was in place, allowing farmers to mitigate credit constraints. As a loan program, the *Fertilizer Credit Program* did not meet its repayment goals, achieving a repayment rate of only 30%. In 2001, the *Fertilizer Support program* (FSP) later renamed *Farmer Input Support Program* (FISP) replaced the *Fertilizer Credit Program*. The FSP represented a substantial financial effort by the Zambian government. Between 2004 and 2011, the FSP alone accounted for 38% of Zambia's agricultural spending and 47% of the government's agricultural sector Poverty Reduction Program (Mason et al., 2013b).

Table A.6: Public budget: Agricultural Sector, 2004/05, Zambia

Program	Percent
Fertilizer Support program	38%
Personal Emolument	21%
Food reserve agency maize marketing	13%
Food Security Pack (PAM) & Emergency Drought Recovery Project	12%
Operational funds	11%
Irrigation development	3%
Irrigation development	3%
Infrastructure	2%

Notes: This table shows the share of the agricultural budget allocated to the most expansive eight investment of the Zambian government in agriculture for the season 2004-2005. Source: World bank Fertilizer toolkit

A.2.2 Timeline of agricultural programs

Zambia has a long history of fertilizer subsidy programs. In the wake of global structural adjustments initiated by the International Monetary Fund (IMF) and the World Bank, Zambia relied heavily on fertilizer subsidy programs to support its agricultural sector. With both a debt relief through the Heavily Indebted Poor Countries program and a transition from conditionality to direct budget support by the World Bank, the country was able to launch the *Fertilizer Support Program* (FSP) and scale up its subsidy agenda increasing from an average of roughly 40,000 metric tons of fertilizer delivered per year to about 65,000 metric tons per year (Minde et al., 2008). The FSP was a cash-only program, unlike previous credit programs; it subsidized fertilizer purchases at a at a 50% rate, focusing on maize production. In 2006 the program was extended to 84,000 metric tons per year and the subsidy was raised to 60% (Mason et al., 2013). In conjunction with the FSP and on a much smaller scale, the Food Security Pack or Program Against Malnutrition (PAM), an agricultural input grant targeting vulnerable households with holdings under 1 hectare was put in place. According to Mason et al. (2013), this program has very low political inference.

According to the program guidelines, first a cooperative or farmer was chosen and then subsidized inputs were given to farmers. Selection criteria apply to both components and include wealth, financial capacity at the cooperative level, field size and financing capacity criteria. Farmer organizations as well as cooperatives are channels through which FSP inputs are distributed. Farmers are required to be members of a cooperative or an organization, and each organization proposes eligible farmers to benefit from the subsidy.
Below is a short presentation of the ex-ante eligibility rules on each layer.

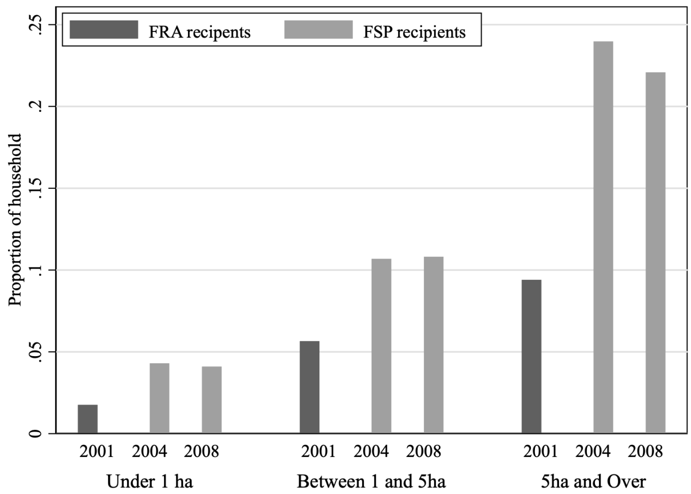
Cooperative or farmer group eligibility rules (quoted from The World Bank, 2010)
1. Written by-laws to manage their funds and have appropriate accountability mechanisms;
2. Have an executive committee structure and should operate a bank account;
3. Demonstrate the need and ability to use the inputs well;
4. Should be registered by the Registrar of Cooperative Societies and Registrar of Societies;
5. Should have no outstanding loans from the past seasons;
6. Should be located in an agricultural area and should be engaged in agricultural activities;
7. Should demonstrate knowledge in cooperative and agribusiness 'management.

Farmer selection criteria (partially quoted from The World Bank, 2010)
1. Be a small-scale farmer and involved in farming within the cooperative coverage area;
2. Has the capacity to grow 1-5 hectares of maize;
3. Have the capacity to pay 40% of the cost of inputs;
4. Should not concurrently benefit from the Food Security Pack;
5. Should not be a defaulter from FRA and/or any other agricultural credit program.

These selection criteria do not fully apply. Figure A.5 shows the distribution of FSP beneficiaries over the years and across land holdings. I use Mason et al. (2013b) definition of land holdings as the sum of cultivated and fallow land. With this definition of landholdings, a striking inadequacy to FSP guidelines arises: a high proportion of the sample's "over five hectares landholders" receive a subsidy, when they should not be eligible. Similarly, a few farmers with landholdings under one hectare receive the subsidy; this proportion is however substantially than that of medium landholders. This limited discrepancy is likely due to the existence of the

PAM program for farmers with landholdings under one hectare.

Figure A.5: Proportion of FRA and FSP recipients across effective field size



Notes: This figure illustrates the proportion of households owning less than 1 hectare, 1-5 hectares, and more than 5 hectares of land who received either the input subsidy program (targeted at landowners with 1-5 hectares) or the FRA program (targeted at those with less than 1 hectare). The majority of households fall into the less than 1 hectare or 1-5 hectare categories, with only a small proportion in the 5+ hectare group, reflecting the panel's sampling strategy.

A.3 More on the reduced-form estimation

A.3.1 Source of variation

The post-harvest panel starts in 2000 (the baseline year) and follows-up with households in 2001, 2004, and 2008. The 2004 surveys constitute the first round of data after the introduction of the subsidy policy. Given this data structure, I observe four area groups: i) areas that never received the ISP subsidy, ii) areas that received the ISP subsidy in 2004, iii) areas that received the ISP subsidy in 2008 and finally iv) areas that received the subsidy in both 2004 and 2008.

To understand further how the treatment and control groups compare, I show in Table A.7 of the Appendix the difference between the early treatment, the late treatment, and the pure control cohorts. These differences in levels do not threaten the validity of the estimates, but they are important for understanding the rollout of the ISP. The areas that received the early treatment (in 2004) bear most resemblance to areas that received a late treatment (in 2008), compared to pure control areas (see column 5 and 6; p-values of the t-tests comparing early treatment, late treatment, and the pure control groups). However, the early treatment group (2004 treatment) is on average richer, and the size of households is larger than the later treatment group (2008 treatment), as shown by the significant p-values in column (6). Households with higher incomes also have household heads with more years of education. While this difference in the number of years of education of the household head is significant, it is small in magnitude, with only 0.3 years of education difference between the early and late treatment cohorts ($p-value = .03$). To account for these imbalances, I control for household size in all my econometric specifications.

Table A.7: Baseline characteristics of households in areas receiving the ISP at different times 2004, 2008

	(1)	(2)	(3)	(4)	(5)	(6)
	Cohorts				t-tests	
Variable in 2001	2004	2008	No ISP	Overall	p-value	
Average in areas	T	C1	C2		T-C1	T-C2
HH size	6.325	5.893	5.683	6.065	0	0
Men headed HH	.801	.777	.742	.779	.066	0
HH out-migrated	.044	.045	.049	.046	.995	.434
# of migrants in HH	.138	.151	.134	.139	.419	.815
Net income$^{\times}$	12.666	9.706	8.642	10.993	0	0
Wealth Index	.141	-.115	-.196	0	0	0
HH head education*	5.654	5.354	4.807	5.354	.03	0
Landholding size	3.215	2.908	2.521	2.958	.005	0
N	4,137	1,213	2,340	7,690		
Control in 2004		Yes	Yes			
Control in 2008		No	Yes			

Notes: This table shows average values for the cohort of areas that received the ISP in the 2004 (early treated), in 2008 (late treated), and areas that never receive the subsidy in the period of the study. The 't-test' column shows individual p-values for tests of covariates. The analysis focuses on the 2004 as a treatment group and I show results for that cohort. In line with Callaway and Sant'Anna (2021), the row 'Control in 2004' shows which cohorts make up the control group for the estimation of the short term effects for the 2004 treatment cohort, while 'Control in 2008' shows which cohorts make up the control group for the estimation of the medium term effects. $^{\times}$: income measured in 100K ZK. *: The household's head education is measured in years.

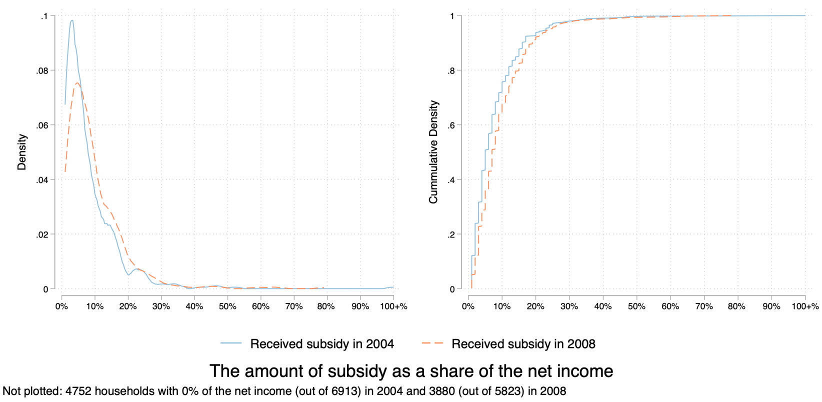


Figure A.7: Total amount of the subsidy over the net income of the household

Notes: This figure plots the density and cumulative distribution of the share of the income that the ISP transfer represent for households that receive the subsidy for each of the two treatment groups (i.e. those who received the subsidy early, in 2004; and those who received the subsidy late, in 2008). The variable plotted is $\frac{\text{Amount of Subsidy}}{\text{Subsidy + Total other income}}$.

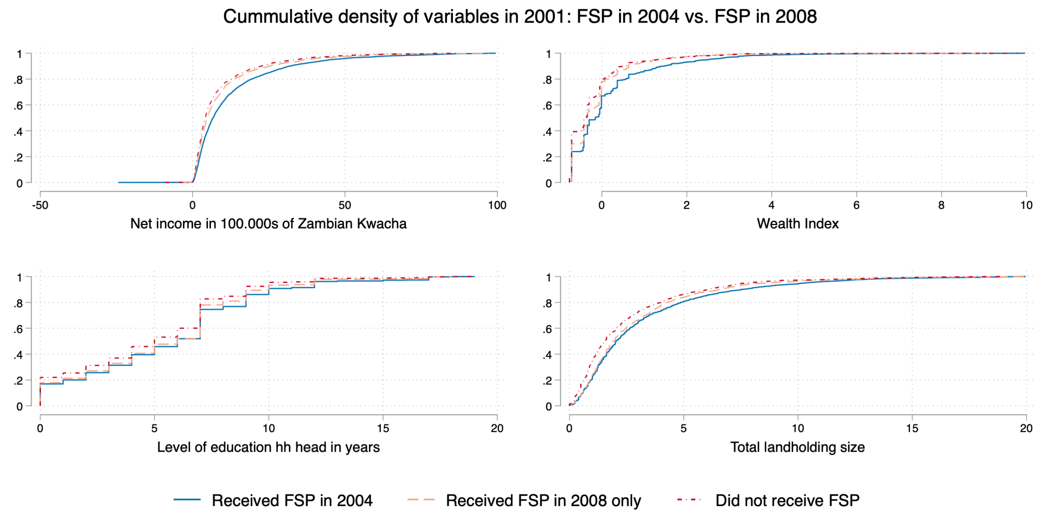


Figure A.6: Baseline characteristics between households in areas that received the subsidy in 2004, 2008 and in areas that did not receive the subsidy

Notes: This figure plots the cumulative distribution in 2001 of the net income, the wealth, the level of education of the household head, and the total landholding size for each of the two treatment groups (i.e. those who received the subsidy early, in 2004; and those who received the subsidy late, in 2008).

Table A.8: Count of areas per treatment years

(1) Years Receiving ISP	(2) Number of areas	(3) % of total areas	(4) Treatment status
2003, 2004, 2007, and 2008	133	33.76%	ISP 2004
Never	115	29.19%	No ISP
2007, and 2008	45	11.42%	ISP 2008
2003, and 2004	28	7.11%	ISP 2004
2004, 2007, and 2008	17	4.31%	ISP 2004
2004, only	16	4.06%	ISP 2004
2008, only	10	2.54%	ISP 2008
2003, 2007, and 2008	7	1.78%	ISP 2008
2003, 2004, and 2008	7	1.78%	ISP 2004
2003, 2004, and 2007	5	1.27%	ISP 2004
2003, only	3	0.76%	No ISP
2007, only	3	0.76%	No ISP
2004, and 2007	3	0.76%	ISP 2004
2004, and 2008	2	0.51%	ISP 2004

Notes: This table shows the count of areas, for each combination of treatment years, ranked by the count of areas in each category. Column (1) shows the combinations of panel years in which at least one household in the area is treated. Column (2) shows the number of areas in each of those treatment combinations, Colum (3) the share of the total areas that is in this treatment combination, and Column (4) the treatment status used in the analysis. The analysis does not account for recall years (2003, and 2007) to measure treatment to avoid conflation of treatment and resale. The treatment years 2003, 2004, 2007, and 2008 correspond to the agricultural seasons 2002/2003, 2003/2004, 2006/2007, and 2007/2008. The agricultural years 2002/2003, and 2006/2007 are based on farmer recall from the panel years 2003/2004, and 2007/2008 respectively. Most areas are treated in one year and get treated in subsequent years. Only a handful of areas get treated in years that are not adjacent.

Table A.9: Descriptive statistics: Check of the randomness of attrition

Panel A: 2001 (marginal migration)

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
		HH stayed		HH migrated		Overall population		Fstat
		Mean	Count	Mean	Count	Mean	Count	Fstat
Data from 2000	# of hh members at	6.45	7347	6.06	352	6.43	7699	3.81
	Gender of hh head	0.78	7347	0.77	352	0.78	7699	0.10
	Age of the hh Head	43.74	7347	40.85	352	43.61	7699	14.08
	Wealth: plough/harrow/oxcart	0.02	7347	-0.25	352	0.01	7699	23.54
	hh head is relative to headman	0.30	6922	.	.	.	.	.
Data from 2001	Dwelling has concrete walls	0.24	6922	.	.	.	.	.
	Dwelling has traditional doors	0.63	6922	.	.	.	.	.
	Dwelling has traditional floor	0.83	6922	.	.	.	.	.
	hh head is single	0.03	6912	.	.	.	.	.
	hh head is monogamous	0.68	6912	.	.	.	.	.
	hh head is polygamous	0.10	6912	.	.	.	.	.
	hh head is divorced	0.06	6912	.	.	.	.	.
	hh head is widowed	0.11	6912	.	.	.	.	.
	hh head is separated	0.01	6912	.	.	.	.	.
	hh head went over primary	0.22	6912	.	.	.	.	.
	Crop land: purchased	0.03	7347	.	.	.	.	.
	Crop land: inherited	0.26	7347	.	.	.	.	.
	Crop land: allocated	0.48	7347	.	.	.	.	.
	Crop land: rented or borrowed	0.04	7347	.	.	.	.	.
	Crop land: walked in	0.11	7347	.	.	.	.	.

Panel B: 2004 (marginal migration)

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
		HH stayed		HH migrated		Overall population		Fstat
		Mean	Count	Mean	Count	Mean	Count	Fstat
Data from 2000	# of hh members at	6.51	6215	6.12	707	6.47	6922	7.43
	Gender of hh head	0.78	6215	0.78	707	0.78	6922	0.01
	Age of the hh Head	44.22	6215	40.71	707	43.86	6922	39.08
	Wealth: plough/harrow/oxcart	0.05	6215	-0.16	707	0.03	6922	25.09
	hh head is relative to headman	0.31	6215	0.21	707	0.30	6922	30.18
Data from 2001	Dwelling has concrete walls	0.24	6215	0.25	707	0.24	6922	1.21
	Dwelling has traditional doors	0.63	6215	0.65	707	0.63	6922	0.68
	Dwelling has traditional floor	0.83	6215	0.78	707	0.83	6922	10.35
	hh head is single	0.03	6207	0.05	705	0.03	6912	7.74
	hh head is monogamous	0.68	6207	0.71	705	0.68	6912	3.68
	hh head is polygamous	0.10	6207	0.07	705	0.10	6912	7.50
	hh head is divorced	0.07	6207	0.06	705	0.06	6912	0.50
	hh head is widowed	0.11	6207	0.10	705	0.11	6912	1.94
	hh head is separated	0.01	6207	0.02	705	0.01	6912	0.71
	hh head went over primary	0.22	6207	0.30	705	0.22	6912	24.22
	Crop land: purchased	0.03	6215	0.03	707	0.03	6922	1.51
	Crop land: inherited	0.29	6215	0.20	707	0.28	6922	23.75
	Crop land: allocated	0.50	6215	0.51	707	0.50	6922	0.26
	Crop land: rented or borrowed	0.04	6215	0.08	707	0.04	6922	30.51
	Crop land: walked in	0.12	6215	0.11	707	0.12	6922	0.18

Panel C: 2008 (marginal migration)

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
		HH stayed		HH migrated		Overall population		Fstat
		Mean	Count	Mean	Count	Mean	Count	Fstat
Data from 2000	# of hh members at	6.69	4744	6.09	1079	6.58	5823	22.97
	Gender of hh head	0.79	4744	0.79	1079	0.79	5823	0.15
	Age of the hh Head	44.66	4744	41.95	1079	44.16	5823	32.30
	Wealth: plough/harrow/oxcart	0.10	4744	-0.14	1079	0.06	5823	46.18
	hh head is relative to headman	0.32	4744	0.26	1079	0.31	5823	14.41
Data from 2001	Dwelling has concrete walls	0.23	4744	0.28	1079	0.24	5823	13.29
	Dwelling has traditional door	0.65	4744	0.53	1079	0.63	5823	59.14
	Dwelling has traditional floor	0.84	4744	0.81	1079	0.83	5823	5.77
	hh head is single	0.03	4738	0.03	1078	0.03	5816	0.66
	hh head is monogamous	0.68	4738	0.70	1078	0.69	5816	1.76
	hh head is polygamous	0.11	4738	0.09	1078	0.11	5816	2.24
	hh head is divorced	0.06	4738	0.08	1078	0.06	5816	4.10
	hh head is widowed	0.11	4738	0.09	1078	0.11	5816	3.23
	hh head is separated	0.01	4738	0.01	1078	0.01	5816	3.94
	hh head went over primary	0.21	4738	0.26	1078	0.22	5816	16.59
	Crop land: purchased	0.01	8268	0.03	1079	0.02	9347	9.67
	Crop land: inherited	0.17	8268	0.27	1079	0.18	9347	60.43
	Crop land: allocated	0.29	8268	0.48	1079	0.32	9347	156.43
	Crop land: rented or borrowed	0.02	8268	0.06	1079	0.02	9347	88.92
	Crop land: walked in	0.06	8268	0.13	1079	0.07	9347	67.43

Notes: This table presents descriptive statistics for households in the study sample, comparing households that migrated in the specified years to those that did not migrate. It allows for a comparison of the characteristics of the migrant households (those who migrated entirely), and those who stayed behind. It provides means and counts for key household characteristics, as well as an overall population mean. The final column displays F-statistics testing for differences between the means of the migrating and non-migrating households. Panel A provides statistics for households that migrated in 2001. Panel B provides statistics for households that migrated in 2004 (excluding those who migrated in 2001). Panel C provides statistics for households that migrated in 2008 (excluding those that migrated in 2001 or 2004).

Table A.10: Quantity and revenue per hectare (ha) in 2001 for ISP recipients in 2004, by migration status in 2008

	Panel A: Household migrated in 2008							
2001 harvest per ha	Outcomes in 2001				Outcomes in 2008			
	Migrated	Stayed	Diff.	P-value	Migrated	Stayed	Diff.	P-value
Total land holdings	9.53	5.28	81%	0			.	
Adults in the household	4.16	4.39	-5%	.033			.	
Kg of maize	1085	1021	6%	0			.	
GV of maize	245032	227986	7%	0			.	
GV of all	348680	346478	1%	.112			.	
GV of cash crops	17804	30761	-42%	.635			.	
GV of other staples	63352	60578	5%	.792			.	
GV of high value food	22492	27153	-17%	.889			.	
	Panel B: Household with 1+ in-migrant in 2008							
2001 harvest per ha	Outcomes in 2001				Outcomes in 2008			
	Inmig.	No inmig.	Diff.	P-value	Inmig.	No inmig.	Diff.	P-value
Total land holdings	5.68	6.07	-7%	0	5.8	5.17	12%	.041
Adults in the household	4.76	3.94	21%	0	6.66	5.21	28%	0
Kg of maize	1033	1028	0%	0	966	878	10%	0
GV of maize	219829	241390	-9%	.004	715023	616373	16%	0
GV of all	341323	352501	-3%	.11	1085416	936524	16%	0
GV of cash crops	38171	19307	98%	0	127045	115201	10%	.001
GV of other staples	58693	63343	-7%	.284	155017	97158	60%	.052
GV of high value food	24630	28461	-13%	.748	87596	105605	-17%	.461
	Panel C: Household with 1+ out-migrant in 2008							
2001 harvest per ha	Outcomes in 2001				Outcomes in 2008			
	Outmig.	No outmig.	Difference	P-value	Outmig.	No out-migrants	Difference	P-value
Total land holdings	5.56	6.28	-12%	0	5.59	5.37	4%	.041
Adults in the household	4.9	3.64	35%	0	6.79	4.42	54%	0
Kg of maize	1078	966	12%	0	1039	708	47%	0
GV of maize	224586	238055	-6%	.001	753906	508279	48%	0
GV of all	349180	343600	2%	.055	1109458	841663	32%	0
GV of cash crops	36798	18515	99%	0	153395	59489	158%	0
GV of other staples	65806	54527	21%	.416	110925	165616	-33%	.001
GV of high value food	21991	32504	-32%	.998	91030	104578	-13%	.599

Notes: This table reports land holdings, the household size, the quantity and gross value (GV) of maize, and other crops per hectare in 2001 and 2008 for ISP recipients in 2004, categorized by household migration status in 2008. The outcomes are presented separately for households that migrated entirely, those with at least one in-migrant, and those with at least one out-migrant. The differences in means (Diff.) are calculated between households that migrated versus stayed (Panel A), households with in-migrants versus those without (Panel B), and households with out-migrants versus those without (Panel C). P-values indicate the statistical significance of these differences. "GV" represents the gross value of crops per hectare, including maize, cash crops, other staples, and high-value food crops. All differences are expressed as percentages where applicable.

Table A.11: Short- and medium-term indirect migration effects of the ISP

Panel A: Callaway and Sant'Anna (2021) DID (area level)

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	1st Stage	Out-migration			In-migration		Agriculture	
	ISP	HH	Individual		Individual		Upgrade	Yield
		left	any	count	any	count	binary	kg/ha
ISP (ITT estimate)		-.05	.05	.13	.01	-.01	.25	257
(2004 & 2008)		(.02)	(.02)	(.05)	(.02)	(.06)	(.01)	(146.98)
Short term		-.02	.03	.09	0	.01	.23	195.47
(2004 effect)		(.02)	(.02)	(.04)	(.02)	(.08)	(.02)	(181.12)
Med. term		-.08	.08	.18	.02	-.04	.27	328.1
(2008 effect)		(.03)	(.03)	(.09)	(.02)	(.06)	(.02)	(159.69)
N HHs		6913	6913	6913	6913	6913	6913	5371
N areas		394	394	394	394	394	394	386
Controls		Yes	Yes	Yes	Yes	Yes	Yes	Yes
Pretrend pval		.54	.45	.59	.61	0	.26	0

Panel A: Instrumental variable (robustness, household level)

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
		Out-migration			In-migration		Agriculture	
		HH	Individual		Individual		Upgrade	
		left	any	count	any	count	binary	
ISP (LATE)		-.02	.25	.72	.09	.29	2.89	
(2004 & 2008)		(.14)	(.16)	(.39)	(.1)	(.25)	(.42)	
Instruments								
MMDwon×dist.	-.0039							
	(.0027)							
Avg.(Price for Fert.)$_{-i}$	.0082							
	(.0011)							
Selected Controls								
Incumbent (MMD) won	.0032							
	(.0074)							
Distance	.0091							
	(.0024)							
N HHs	6922	6922	6922	6922	6922	6922	6922	
N areas	394	394	394	394	394	394	394	
Controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes	
F-stat	30.3							

Panel B: DIDIV using IV from Panel B (robustness, area level)

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
		Out-migration			In-migration		Agriculture	
		HH	Individual		Individual		Upgrade	
		left	any	count	any	count	binary	
ISP (LATE)		-.02	.02	.08	0	-.05	.13	
(2004 & 2008)		(.01)	(.03)	(.04)	(0)	(.02)	(.02)	
Short term		-.01	.03	.09	0	-.02	.12	
(2004 effect)		(.01)	(.02)	(.06)	(.01)	(.02)	(.03)	
Med. term		-.03	0	.08	0	-.08	.14	
(2008 effect)		(.02)	(.03)	(.04)	(.01)	(.02)	(.02)	
N HHs		6913	6913	6913	6913	6913	6913	
N areas		394	394	394	394	394	394	
Controls		Yes	Yes	Yes	Yes	Yes	Yes	
Pretrend pval		.05	.98	.41	.38	.12	0	

Notes: The table shows estimates for farmers treated in 2004. ISP stands for input subsidy program. Columns (2) show the estimates for household out-migration moving entirely at the extensive margin, columns (3) whether the household has any out-migrants, columns (4) the number of out-migrants within households, columns (5) whether the household has any additional members, and finally columns (6) the number of additional individuals added to the household. For each outcome, I report the difference in difference (DID) at the area level (Equation 3) in Panel A, the instrumental variable (IV) estimates at the household level (Equation 4) in Panel B, and instrumented DID estimates (DIDIV) in Panel C (Equation 6). Main effects aggregate estimates from 2004 and 2008. Short-term effects are for 2004, and medium-term effects are for 2008. Panel B instruments receipt of the ISP in 2004, and estimate the effect across years. Standard errors (SE) are in parenthesis, and clustered at the area level. The SE for the DIDIV are obtained via bootstrap (300 repetition of the first-stage regression, the classification, and the DID estimation using Callaway and Sant'Anna (2021)). Pre-trend p-values are from the Chi-square test. Controls include baseline household size, incumbent election victory and the head of household's education level.

Table A.12: **Actual treated areas vs. predicted treatment areas from the instrumental variables**

		Predicted share of HHs treated (DIDIV)			
		Never	Early treated	Late treated	Total
HHs in Treatment	Never	82%	16%	2%	100%
	Early treated (2004)	22%	69%	8%	100%
	Late treated (2008)	48%	23%	29%	100%

Notes: This Table compares the actual areas that are treated to areas that are predicted with the IV to be treated (and used in the instrumented difference in differences). The rows are the actual treatment cohorts (never treated, treated early, and treated late), and the columns are the treatment prediction using the instrumental variable. The percentages are the percentage of household who are classified across treatment group and end up predicted in each treatment group. For example, among the households who are in areas that are never treated 82% are classified as never treated based on the instrumental variable, 15% as early treated (i.e. treated as early as 2004) and late treated (i.e. treated in 2008 only).

A.4 Comparing households with different labor allocation choices

Table A.13: Characteristics of households across upgrading decisions

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Upgrade occurred...	Never		... in 2004		... in 2008		... in 2004+2008	
Mean at	Baseline (2001)	Endline (2008)	Baseline (2001)	Endline (2008)	Baseline (2001)	Endline (2008)	Baseline (2001)	Endline (2008)
				Household characteristics				
HH size	5.73	5.48	6.59	6.30	6.73	6.38	7.78	7.30
Share upgraders	.18	0	.46	0	.46	1	.72	1
Share with in-migrant	0	.01	0	.01	0	.05	0	.05
Share with out-migrant	.07	.36	.10	.40	.10	.56	.11	.62
Number Out-migrants	.12	.94	.12	1.25	.11	1.22	.18	1.42
Education out-migrants	.40	0	.46	0	.41	0	.75	0
				Household's head characteristics				
HHH education	5.07	4.51	6.57	5.69	5.71	5.90	6.65	6.71
Share woman	.20	.20	.17	.15	.14	.15	.14	.18
				Farming characteristics				
Total landholding	2.39	1.83	2.86	2.20	3.40	2.89	4.69	4.28
Share of maize	.56	.52	.56	.55	.55	.55	.57	.60
Fertilizer per ha maize	60	33	138	114	110	229	192	297
Fertilizer per ha total	27	12	62	54	51	107	103	163
Maize Yields	1622	1321	1962	1524	1878	1953	2190	2324
				Financial characteristics				
Remittances received	21349	97548	34631	133835	28419	155842	34867	325285
Remittances sent	13986	61467	20722	143945	23642	228724	34946	326411
Wealth index 2001	-.10	-.17	.28	.28	.18	.18	.76	.76
N	2473	1567	624	624	407	407	633	633

Notes: This table shows the raw mean of demographic, agricultural production and financial characteristics at baseline (in 2001) and endline (in 2008) for households that made decisions to upgrade their agricultural technology. I show this mean for three different decision points: Columns (1) and (2) are those who never upgraded, Columns (3) and (4) are those who upgraded in 2004, and did not upgrade subsequently, Columns (5) and (6) are the households who only upgraded in 2008 and finally Columns (7) and (8) are those who upgraded both in 2004 and 2008. This table shows that upgraders are on average richer than non-upgraders. If further shows that those who upgraded in both 2004 and 2008 and substantially richer than other households. And that at baseline the households with most labor (larger household sizes), and land had high yields and were upgraders.

Table A.14: Characteristics of households across out-migration decisions

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Out-migration occurred...	Never		... in 2004		... in 2008		... in 2004+2008	
Mean at	Baseline (2001)	Endline (2008)	Baseline (2001)	Endline (2008)	Baseline (2001)	Endline (2008)	Baseline (2001)	Endline (2008)
				Household characteristics				
HH size	5.09	6.17	7.03	6.13	6.26	6.05	9.05	6.48
Number Out-migrants	.07	0	.23	0	.09	1.96	.25	2.25
Share upgraders	.25	.23	.37	.23	.37	.37	.47	.50
Share with in-migrant	0	.01	0	.01	0	.02	0	.07
Share with out-migrant	.05	0	.18	0	.07	1	.17	1
Education out-migrants	.28	0	.91	0	.23	0	.93	0
				Household's head characteristics				
Share woman	.15	.10	.21	.17	.20	.25	.18	.25
HHH education	5.86	5.55	5.69	5.25	5.28	5.19	5.5	5.80
				Farming characteristics				
Total landholding	2.38	2.13	3	2.33	3.26	2.72	4.11	3.39
Share of maize	.56	.52	.56	.56	.55	.55	.57	.58
Fertilizer total	46	56	50	72	44	66	58	93
Fertilizer maize	99	121	110	164	97	147	123	181
Maize Yields	1702	1624	1871	1808	1867	1722	1996	1824
				Financial characteristics				
Remittances received	23105	101743	35749	181735	19933	140002	35662	274593
Remittances sent	17706	88786	17446	201084	17140	138898	30326	268956
Wealth index 2001	-.05	-.05	.15	.15	.11	.11	.55	.55
N	2080	1174	610	610	812	812	635	635

Notes: This table shows the raw mean of demographic, agricultural production and financial characteristics at baseline (in 2001) and endline (in 2008) for households that made decisions to have out-migrants. I show this mean for three different decision points: Columns (1) and (2) are those who never sent out-migrants, Columns (3) and (4) are those who sent out-migrants in 2004, and did not send out-migrants subsequently, Columns (5) and (6) are the households who only sent out-migrants in 2008 and finally Columns (7) and (8) are those who sent out-migrants both in 2004 and 2008. This table shows that households that sent out-migrants are on average richer than those he did not. If further shows that those who sent out-migrants in both 2004 and 2008 and substantially richer than other households. And that at baseline the households with most labor (larger household sizes), tend to send more out-migrants. Finally, households with out-migrants both send and receive more remittances.

Table A.15: Characteristics of households across in-migration decisions

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
In-migration occurred...	Never		... in 2004		... in 2008		... in 2004+2008	
Mean at	Baseline (2001)	Endline (2008)	Baseline (2001)	Endline (2008)	Baseline (2001)	Endline (2008)	Baseline (2001)	Endline (2008)
				Household characteristics				
HH size	6.57	6.23	5.94	.	7.11	6.80	7	6.36
Share upgraders	.37	.40	.34	0	.40	.51	.38	.38
Share with in-migrant	0	0	0	0	0	1	0	0
Share with out-migrant	.09	.52	.10	0	.20	.67	.09	.80
Number Out-migrants	.12	1.08	.14	.	.33	1.70	.10	2.05
Education out-migrants	.43	0	.51	.	1.38	0	.50	0
				Household's head characteristics				
HHH education	5.46	5.44	6.11	.	5.01	5.15	5.21	5.25
Share woman	.17	.20	.20	0	.33	.41	.25	.34
				Farming characteristics				
Total landholding	3.17	2.58	2.54	.	3.88	4.32	3.27	2.97
Share of maize	.55	.56	.57	.	.60	.58	.56	.55
Fertilizer per ha maize	105	142	99		99	201	107	180
Fertilizer per ha total	47	69	48		53	93	51	77
Maize Yields	1843	1716	1755		1626	1945	1931	1737
				Financial characteristics				
Remittances received	23137	159927	34464		30086	227614	34895	238670
Remittances sent	17644	155509	22567		23722	173409	26658	231895
Wealth index 2001	.14	.14	.12	.12	.5	.5	.27	.27
N	2212	2212	508	508	83	83	188	188

Notes: This table shows the raw mean of demographic, agricultural production and financial characteristics at baseline (in 2001) and endline (in 2008) for households that made decisions to host in-migrants. I show this mean for three different decision points: Columns (1) and (2) are those who never host in-migrants, Columns (3) and (4) are those who host in-migrants in 2004, and did not host in-migrants subsequently, Columns (5) and (6) are the households who only host in-migrants in 2008 and finally Columns (7) and (8) are those who host in-migrants both in 2004 and 2008. This table shows that households that host in-migrants are on average similar in wealth to those who did not. If further shows that at baseline the households with most labor (larger household sizes), tend to host more in-migrants. These estimates should be interpreted carefully as the in-migration variable is a proxy of true in-migration.

A.5 Mechanisms

A.5.1 More details on resale markets

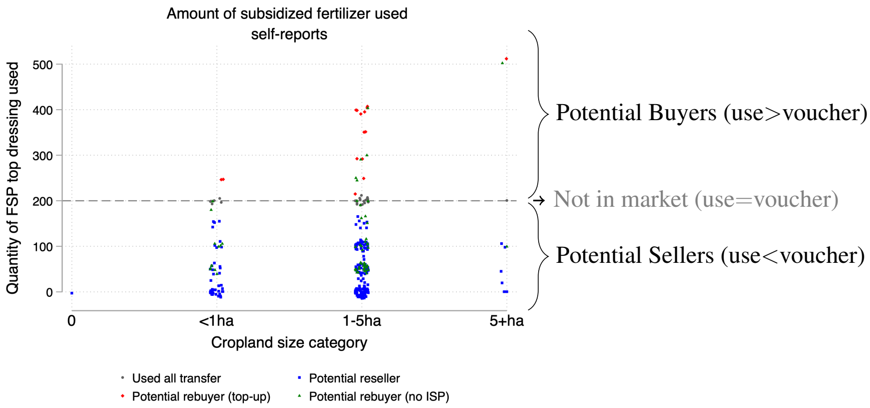
Figure A.9 plots the self-reported source of fertilizer used in farms. Panel 1 shows the source of fertilizer used in 2004 for households that did not migrate in 2008, and Panel 2 shows the sub-sample of households that migrated in 2008. Each graph plots fertilizer used by farmers owning farms of different sizes against the amount of fertilizer used from each source.[51]

On the far left two graphs, I plot the fertilizer used on the farm, stemming from the fertilizer subsidy program. The red-dashed line is the 200kg voucher received by all farmers. Any farmer group using more than this amount has likely obtained their vouchers from other farmers (or through other unknown means), and any farmers using less than the red-dashed line have

[51] In the sample of Zambian small holders, only 20% report receiving the subsidized fertilizer on time for the 2003-2004 agricultural season. This implies that a large amount of fertilizer used in a given season is from left overs from the previous season. This further implies that to use the fertilizer at the appropriate time in the planting season, most farmers need use left-over fertilizer (of lower quality), commercial or resale markets. Another implication of this delay is that migration becomes in this case more attractive than agriculture because of the lost revenue in agriculture.

potentially sold their voucher to another farmer. The far-right panel plots the distribution of farm sizes in the sample. Most farms in the sample (1-5 hectares) use exactly the amount provided via the voucher subsidy and supplement with commercial markets. However, some farmers — with very large farms — use more subsidized fertilizer than officially received, and farmers with small farms use less than they have received. This implies a redistribution — across farmers, based on farm sizes and needs.

Panel A: Top-dressing fertilizer



Panel B: Basal fertilizer

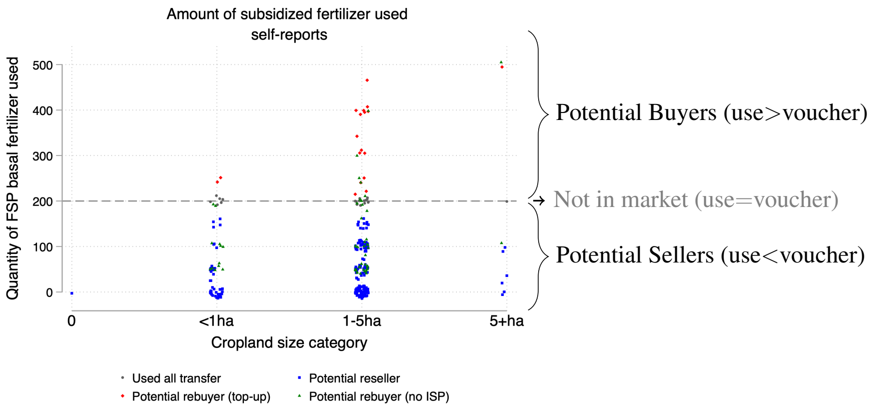


Figure A.8: Subsidized fertilizer used on farm compared to quantity transferred

Notes: This figure shows the distribution of fertilizer used, against the (official) ISP fertilizer quantity for top-dressing fertilizer (top row) and basal fertilizer (bottom row). Using self-reported data on top-dressing fertilizer for the year 2004 from the Post-harvest survey of 1999-2000 and its supplemental surveys (panel). The horizontal line is 200kg (the amount received by farmers). Each dot represents the quantity of fertilizer used by one household with a random small perturbation to get a clearer representation of the number of households. The potential resellers are those who report to have used less than the 200kg received, and the potential re-buyers are those who report using more than 200kg.

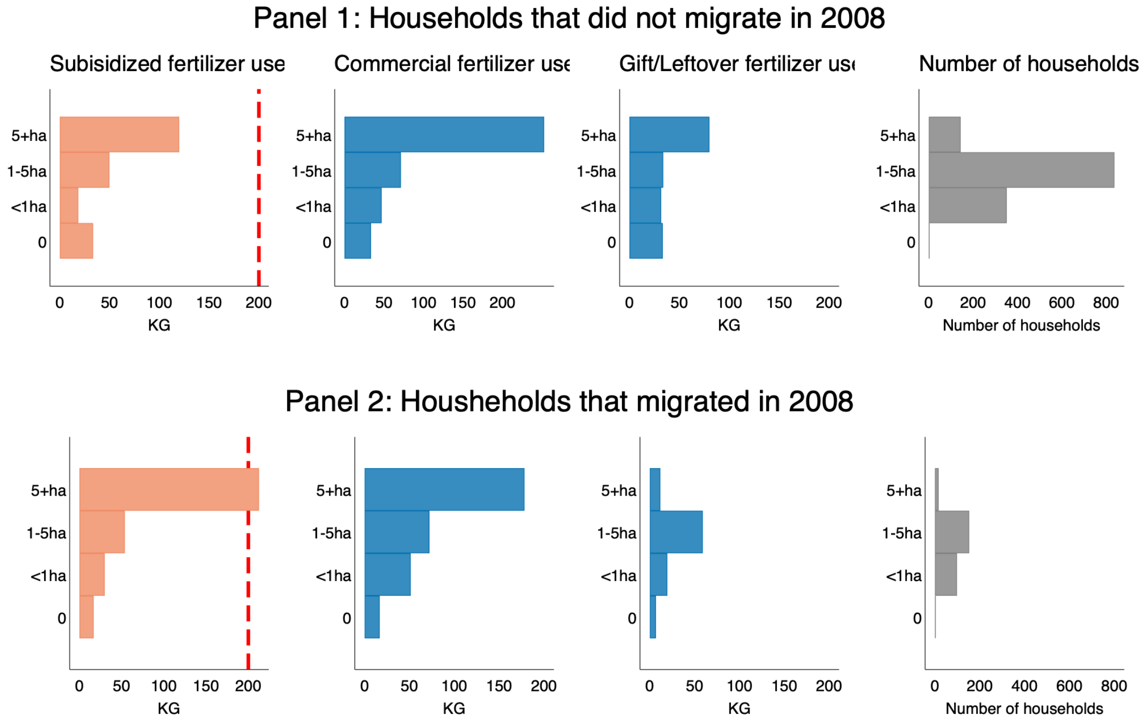


Figure A.9: Source of fertilizer used on the farm in 2004

Notes: This figure illustrates the sources of fertilizer used in 2004 by households that did not migrate (top row) and those that migrated in 2008 (bottom row), if they used any fertilizer at all. The first column represents ISP fertilizer use, the second column shows commercial fertilizer use, the third column reflects fertilizer obtained as a gift or leftover from previous seasons (low quality), and the fourth column depicts the distribution of farm sizes. Most farms are between 1 and 5 hectares. The figure highlights that farmers who migrated tended to use marginally more fertilizer from the subsidy program in 2004 compared to their non-migrant counterparts. It also shows that fertilizer use varies across different farm sizes, with smaller farms using lower quantities of fertilizer, often well below the allocated amount (indicated by the dashed vertical line), suggesting the potential for resale. The data is self-reported from the 1999-2000 post-harvest survey and its supplemental panel surveys.

A.6 SUTVA test for difference and difference

A first issue with the estimation of the difference-in-differences is the possibility that the stable unit treatment value assumption (SUTVA) does not hold. In the Zambian ISP setting that would imply two things: a) the spillover effects could occur across treatment units, i.e. farmers in treated areas selling to farmers in control areas, and thus relaxing credit constraints for farmers in the treated areas, while increasing access to fertilizer in control areas. With these spillovers, migration is overestimated — as the control group increases its demand and thus puts pressure on fertilizer prices — and upgrading is underestimated as the control group would adopt because of the ISP; b) the roll-out of the subsidy should also affect the network of fertilizer suppliers, thus making it easier for farmers in control groups to adopt fertilizer due to the ISP.

Both channels — through trade across treatment status and through the network of suppliers — could bias the results presented in the paper. There are however limitations in the panel that hamper my ability to check for the existence of these sources of the SUTVA violation.

The sampling of areas[52] is such that areas are unlikely bordering each other. However, to check for the importance of spillovers in our sample, I look at the variations in the price of commercial fertilizer across high and low treatment density areas. If spillovers are important, the expectation is that high treatment density areas to have more variations in prices (both a potential increase in prices if demand effects dominate or decrease in prices if supply network effects dominate). The results are presented in Figure A.10.

Prices have not significantly changed in for control households located in areas with a high concentration of ISP recipients in 2004. Albeit representing a large portion of farmers in Zambia, the 1 to 5 hectare holders do not have as much market power as would larger farms, and in 2004, at the onset of the ISP the effect of the subsidy may not have been as important on national prices as they would have been in the later years of the ISP.

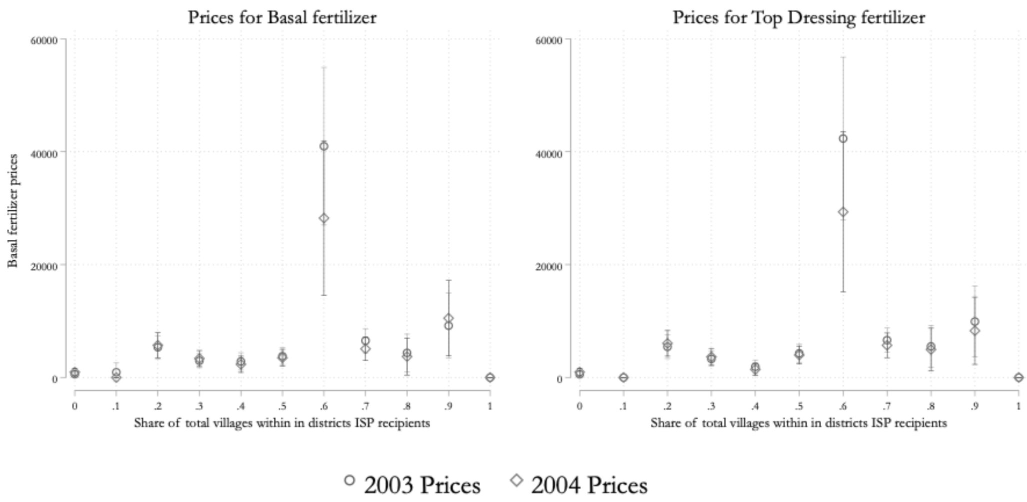


Figure A.10: Sutva test: change in fertilizer prices for non-ISP recipients, depending on concentration of ISP areas in districts

Notes: This figure shows the relationship between fertilizer prices and the share of areas within districts that are ISP recipients, for both Basal (left panel) and Top-Dressing fertilizer (right panel). Circles denote 2003 prices, while diamonds represent 2004 prices. The vertical lines indicate 95 percent confidence intervals. The figure examines potential spillover effects from the ISP rollout, which could arise if fertilizer from treated areas was sold in control areas or if the ISP altered the network of fertilizer suppliers. Prices have not significantly changed for control households located in areas with a high concentration of ISP recipients in 2004, suggesting that spillovers did not have a substantial effect on commercial fertilizer prices during this period.

[52]These areas correspond to Standard Enumeration Areas (SEA) and are the least aggregated and include typically one area (see Table A.1 of the Appendix).

Table A.16: Impact of the Volume of Subsidy on Migration Decisions of Individuals

	(1) Indiv - Rate Out	(2) Indiv - Count Out
Extra dollar subsidy	0.00257***	0.0105***
	(0.000360)	(0.00152)
Square extra dollar subsidy	-1.71 $\cdot 10^{-06}$***	-3.10 $\cdot 10^{-6}$*
	(3.77 $\cdot 10^{-7}$)	(1.84 $\cdot 10^{-06}$)
Total in-kind and cash remittances	0.000193**	0.000394
	(7.98e-05)	(0.000254)
Constant	0.0930***	0.301***
	(0.000663)	(0.00276)
Observations	31,078	31,078
R-squared	0.008	0.020
Number of hhcode	11,166	11,166
Household and year FE	yes	yes

Notes: This table presents the impact of the volume of subsidy on migration decisions of individuals. Column (1) reports the results for the individual rate of out-migration (Indiv - Rate Out), and column (2) reports the results for the individual count of out-migrants (Indiv - Count Out). The coefficients for the extra dollar subsidy and its squared term indicate a nonlinear effect on migration decisions, with positive but diminishing returns. The total in-kind and cash remittances variable shows a positive effect on migration in column (1), though the effect is not statistically significant in column (2). All regressions include household and year fixed effects. Standard errors are robust and are reported in parentheses. p<0.01, p<0.05, and p $<$ 0.1 denote statistical significance at the 1

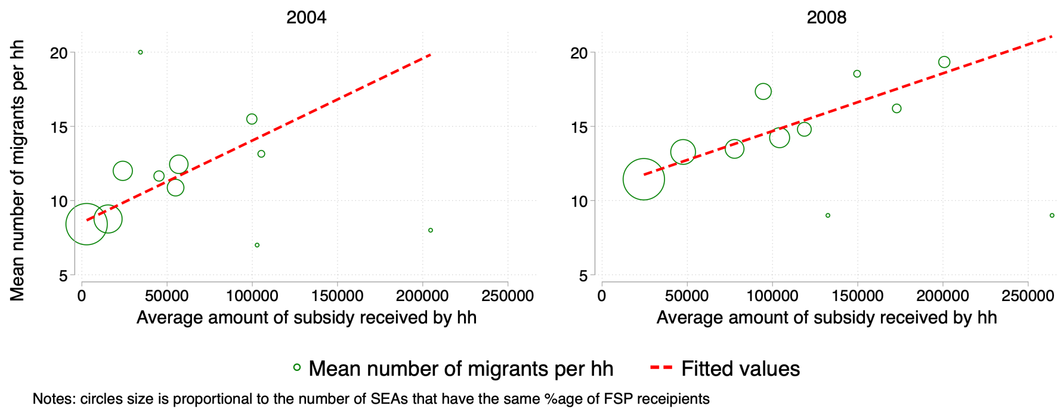


Figure A.11: Impact of the Volume of Subsidy on Migration Decisions of Individuals
Notes: This figure plots the correlation between the computed amount of the transfer through he ISP, and the number of migrants per household in 2004 (left) and in 2008 (right). It shows that (a) there is a positive correlation between the amount received and the number of migrants, consistent with the fact that farmers who receive larger transfers, generate more income to fund migration, and (b) that the correlation is stronger for those who received the ISP in 2004.

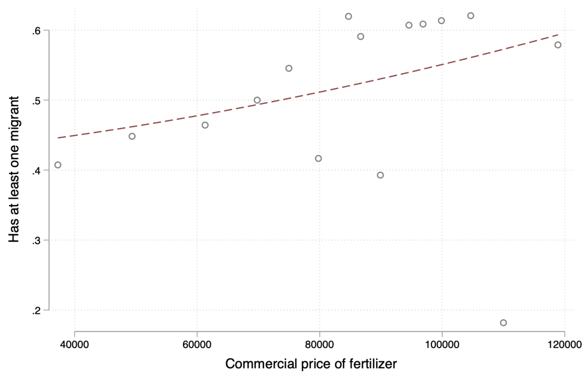


Figure A.12: Commercial price of fertilizer vs. extensive individual migration

Notes: This figure shows the correlation between the commercial price of fertilizer, and the likelihood of sending migrants out of the area.

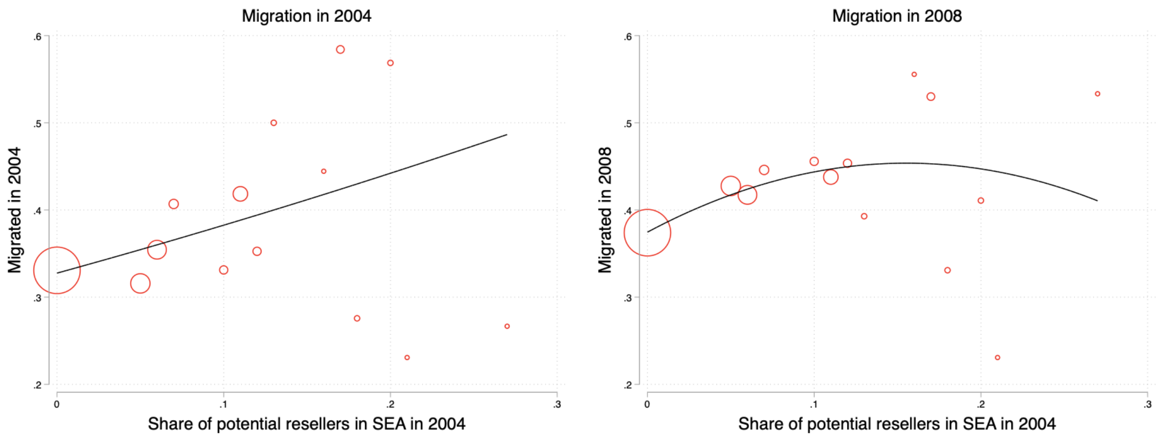


Figure A.13: Migration in 2004 and 2008 by share of potential resellers in an areas

Notes: This figure shows plots on the left the correlation between migration and the share of farmers who use less fertilizer than they (should have) received —these are potential resellers. The left panel plots this correlation for 2004 migration, and the right panel for migration that occurred in 2008, with respect to the share in 2008. This figure allows us to understand the correlation between potential sales with short term (left) and long term (right) migration. The underlying data are self-reported data from the Post-harvest survey of 1999-2000 and its supplemental surveys (panel). In 2004, areas with the most potential resellers are also those with the most households sending out-migrants. This increase tapers off as time goes by (see right-hand side graph in Figure A.13). The migrants of 2008 are likely migrating due to increased productivity rather than a relaxation of the credit constraint for migration.

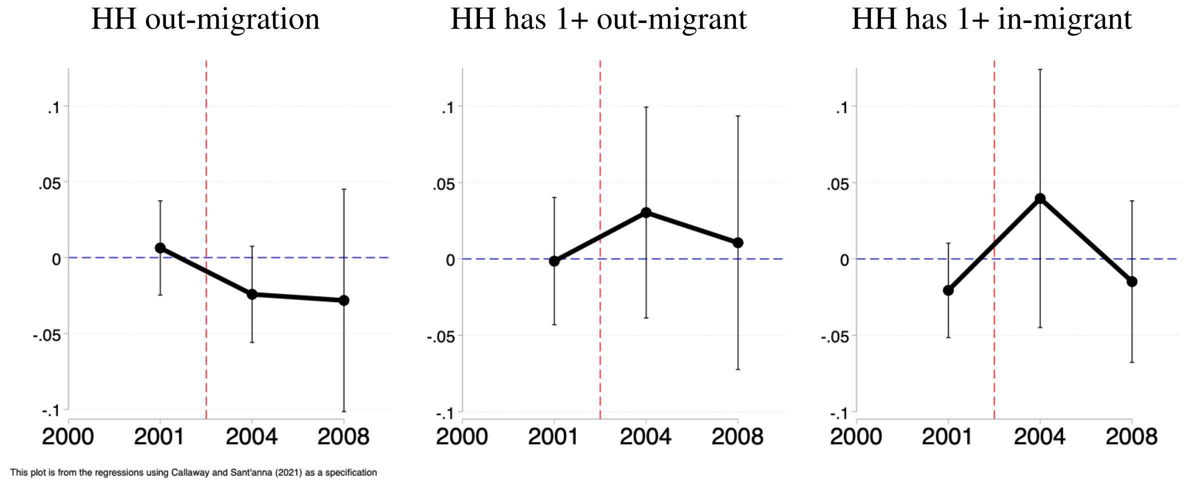


Figure A.14: Effects shutting down persistent short-term migration

Notes: This figure shows the treatment effects from limiting the sample to areas that were treated only in 2004 and were not treated again in the 2006-2007 or 2007-2008 periods. It shows that the long term effects are not due to a succession of short term effects. The x-axis represents years from 2000 to 2008, while the y-axis indicates the estimated treatment effects on the outcome of interest. The red dashed vertical line marks the year of treatment, 2004, while the blue dashed horizontal line represents zero treatment effect. Each plot corresponds to a different margin of migration (from left to right): (i) en-masse migration, (ii) sending out-migrants, and (iii) hosting in-migrants. The figure highlights that treatment effects persist through 2008, even though the areas were treated only once. Error bars represent 95 percent confidence intervals.

B A model of selection

B.1 Solutions for traditional agriculture

Unconstrained households: the interior solution

When the household's labor units in agriculture, or credit constraints are not binding, the household's set of choices is in the interior solution, leading to the following first order conditions:

$$\frac{\partial \pi_{i,T}^{u*}}{L_{i,A}} = paL_{i,A}^{\gamma-1}X_i^{\delta} - \tilde{w}_i = 0; \tag{B.1}$$

Which leads to the household to choose the below levels of migration, and leading to the profits $\pi_{i,T}^{u*}$

$$\text{Unconstrained migration } L_{i,M}^{u*} = L_i - \left(\frac{\gamma paX_i^{\delta}}{\tilde{w}_i}\right)^{\frac{1}{1-\gamma}} \tag{B.2}$$

$$\text{Unconstrained profit} \qquad \pi_{i,T}^{u*} = \gamma^{\frac{\gamma}{1-\gamma}}(1-\gamma\tilde{w}_i)\left(\frac{paX_i^{\delta}}{\tilde{w}_i{}^{\gamma}}\right)^{\frac{1}{1-\gamma}} + \tilde{w}_iL_i + q_v\bar{f} - c_i^M \tag{B.3}$$

Labor constraints bind

If the household that has an optimal labor demand that is larger than its endowment of labor units ($L_{i,A}^{*} > L_i$), or a household for which the credit constraint binds (i.e. $PY_i + q_v\bar{f} > c_i^M$) meaning that the household would want to migrate but cannot afford to), its constrained migration units of labor, and profits are the following:

$$\text{Constrained migration } L_{i,M}^{c*} = 0 \tag{B.4}$$
$$\text{Constrained profit } \quad \pi_{i,T}^{c*} = paL_i^\gamma X_i^\delta + q_v \bar{f} \tag{B.5}$$

B.2 Solutions for upgraded agriculture

Unconstrained households: the interior solution

When the household's labor units in agriculture, or credit constraints are not binding, the household's set of choices is in the interior solution. The household optimizes over its labor units and its fertilizer use, leading to the following first order conditions:

$$\frac{\partial \pi_{i,T}^{u*}}{L_{i,A}} = \alpha p A_i L_{i,A}^{\alpha-1} F_i^\beta X_i^{1-\alpha-\beta} - \tilde{w}_i = 0; \tag{B.6}$$
$$\frac{\partial \pi_{i,T}^{u*}}{F_i} = \beta p A_i L_{i,A}^{\alpha} F_i^{\beta-1} X_i^{1-\alpha-\beta} - q_v = 0; \tag{B.7}$$

These FOCs, lead to the optimal unconstrained solutions over migration, fertilizer use, the resulting profits to be:

$$\text{Unconstrained migration } L_{i,M}^{u*} = L_i - X_i \left[\left(\frac{\beta}{q_v}\right)^\beta \left(\frac{\alpha}{\tilde{w}_i}\right)^{1-\beta} pA_i \right]^{\frac{1}{1-\alpha-\beta}}, \tag{B.8}$$

$$\text{Unconstrained fertilizer } \quad F_i^{u*} = X_i \left[\left(\frac{\beta}{q_v}\right)^{1-\alpha} \left(\frac{\alpha}{\tilde{w}_i}\right)^{\alpha} pA_i \right]^{\frac{1}{1-\alpha-\beta}}, \tag{B.9}$$

$$\text{Unconstrained profit } \quad \pi_{i,F}^{u*} = X_i \left[pA_i \frac{1}{q_v^\beta \tilde{w}^\alpha} \right]^{\frac{1}{1-\alpha-\beta}} \Psi + q_v \bar{f} + L_i \cdot \tilde{w}_i - C_v^F - c_i^M, \tag{B.10}$$

where $\Psi = \beta^{\frac{\beta}{1-\alpha-\beta}} \cdot \alpha^{\frac{\alpha}{1-\alpha-\beta}} - \beta^{\frac{1-\alpha}{1-\alpha-\beta}} \cdot \alpha^{\frac{\alpha}{1-\alpha-\beta}} - \beta^{\frac{\beta}{1-\alpha-\beta}} \cdot \alpha^{\frac{1-\beta}{1-\alpha-\beta}}$.

Labor constraints bind

If the household has an optimal labor demand that is larger than its endowment of labor units ($L_{i,A}^* > L_i$), or has a binding credit constraint (i.e. $PY_i + q_v \bar{f} > c_i^M$ meaning that the household would want to migrate but cannot afford to), its constrained migration units of labor, and profits are the following:

$$\text{Constrained migration } L_{i,M}^{c*} = 0 \tag{B.11}$$

$$\text{Constrained fertilizer } \quad F_i^{c*} = \left[\frac{pA_i X_i^{1-\alpha-\beta}}{q_v} \right]^{\frac{1}{1-\beta}} \tag{B.12}$$

$$\text{Profit } \quad \pi_{i,F}^{c*} = \left(\beta^{\frac{1}{1-\beta}} - \beta^{\frac{1}{1-\beta}}\right) \left[\frac{pA_i X_i^{1-\alpha-\beta}}{q_v} \right]^{\frac{1}{1-\beta}} + q_v \bar{f} - C_v^F \tag{B.13}$$

Proposition 1 *There exist at most two cut-offs in X_i that determine whether the household has any migrants. For X_i lower than a cuttoff X_i^L, the household is not productive enough and* *thus cannot afford to migrate (the credit constraint is binding). Similarly for X_i higher than X_i^H, the household is very productive in agriculture, and no household member migrates. For values of X_i between X_i^L and X_i^H the number of migrating labor units is an inverted U-shape.*

Proof of Proposition 1.

$$\frac{\partial \pi_{i,T}^{u*}}{X_i} =$$

■

Proposition 2 *For the unconstrained household, there exist at most two cut-offs in $\tilde{w}_i$ that lead to different migration decisions. For $\tilde{w}_i$ lower than $\tilde{w_i^L}$, the household specializes in agriculture, and for $\tilde{w}_i$ higher than $\tilde{w_i^H}$, the entire household migrates. For values of $\tilde{w}_i$ between $\tilde{w_i^L}$ and $\tilde{w_i^H}$ the number of migrating labor units is increasing.*

Proof of Proposition 2. an interior solution requires that $L_{i,M} > 0$, or equivalently, $L_{i,A} < L_i$. Taking the derivative of ex-post returns with respect to $\tilde{w}_i$:

$$\frac{\partial \pi_{i,T}^{u*}}{\tilde{w}_i} = \frac{\gamma^{\frac{\gamma}{1-\gamma}}(1-\tilde{w}_i)}{(\gamma-1)\tilde{w}_i}\left(\frac{paX_i^{\delta}}{\tilde{w}_i}\right)^{\frac{1}{1-\gamma}} + L_i;$$

For a given endowment of land and labor units, if $\tilde{w}_i$ is under a threshold $\tilde{w_i^L}$, $1-\tilde{w}_i$ is positive, making $\frac{\gamma^{\frac{\gamma}{1-\gamma}}(1-\gamma\tilde{w}_i)}{(\gamma-1)\tilde{w}_i}$. Above $\tilde{w_i^L}$, the household returns to migration are large enough to send increasing number of labor units, until all its units migrate, which is reached when $\tilde{w}_i > \tilde{w_i^H}$ ■

Proposition 3 *When the subsidy is introduced and for migration costs that sufficiently low, resale markets make the number of households who can afford to migrate larger, thus increasing migration rates within an area.*
For some households with very low migration costs, the entire households can migrate, funding migration entirely with the proceed from the resale of the subsidized fertilizer.

Proof of Proposition 3. Without the subsidy $q\bar{f} = 0$. Equation 9 shows for households with a binding credit constraint, i.e. $paL_{i,A}^{\gamma}X_i^{\delta} + q\bar{f} < c_i^M$, migration does not occur. Note that:

$$\forall \bar{f} > 0; q > 0 : paL_{i,A}^{\gamma}X_i^{\delta} + q\bar{f} > paL_{i,A}^{\gamma}X_i^{\delta} \tag{B.14}$$

$$\Rightarrow \sum_{i=1}^{N_v} 1_{\{paL_{i,A}^{\gamma}X_i^{\delta}+q\bar{f}>c_i^M\}} \geq \sum_{i=1}^{N_v} 1_{\{paL_{i,A}^{\gamma}X_i^{\delta}>c_i^M\}} \tag{B.15}$$

Which implies that when households can trade their fertilizer in resale markets, they end up with more disposable income. Some households for which the credit constraint binds prior to the subsidy see their constraints relaxed, and they can afford to migrate. ■

Proposition 4 *If q^* is sufficiently low, a household that has high returns to migration want to put all their labor into migrating but need to fund it by using some in agriculture for profits. Said more precisely, their unconstrained labor choice would cause profit to fall below the amount required by credit constraint. Therefore, they set their labor to exactly cover the cost of migrating, making some households' optimal choice to both upgrade & migrate. This household's upgrading decision may lead to the household overusing fertilizer, such that $F_i > F_i^*$.*

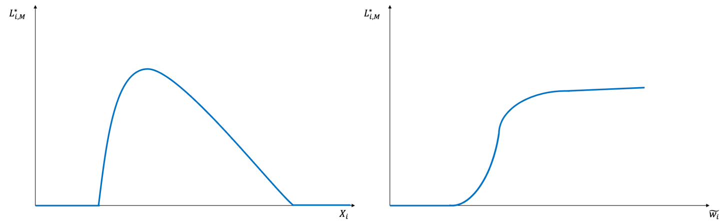


Figure B.1: Comparative statics

Notes: This figure plots the number of labor units within households migrating as a function of landholding X_i on the left panel, and as a function of the returns to migration $\tilde{w}_i$ on the right panel.

Proof of Proposition 4. The credit constraint is of the form $pY_i + q\bar{f} \geq c_i^M$ where $Y_i = a \cdot L_{i,A}^{\gamma} X_i^{\delta}$ for non-upgraders, and $Y_i = A_i \cdot L_{i,A}^{\alpha} F_i^{\beta} X_i^{1-\alpha-\beta}$ for upgraders. For households with A_i large enough, the household upgrades (see Equation 12).
Households who have high returns to migration ($\tilde{w}_i$), and whose optimal interior choice is binded by the credit constraint will increase their agricultural production just enough to cover the migration cost.
For non-upgraders, this means that $paL_{i,A}^{\gamma} X_i^{\delta} + q\bar{f} = c_i^M$, which implies $L_{i,A} = \frac{c_i^M - q\bar{f}}{X_i^{\delta}}^{\frac{1}{\gamma}}$.
For upgraders, this means that $pA_i \cdot L_{i,A}^{\alpha} F_i^{\beta} X_i^{1-\alpha-\beta} + q\bar{f} = c_i^M$. For the extreme where $q = 0$, we have $L_{i,A} = \left(\frac{\tilde{w}}{\alpha}\right)^{\frac{1}{\alpha}}$ and $F_i = \left(\frac{c_i^M \alpha}{\tilde{w} p A_i X_i^{1-\alpha-\beta}}\right)^{\frac{1}{\beta}}$

Both solutions deviate from the optimal solutions, and for high enough costs of migration, and returns to migration, there may be some over-investment in the upgraded agriculture, due to this shadow cost of the constraint.

■

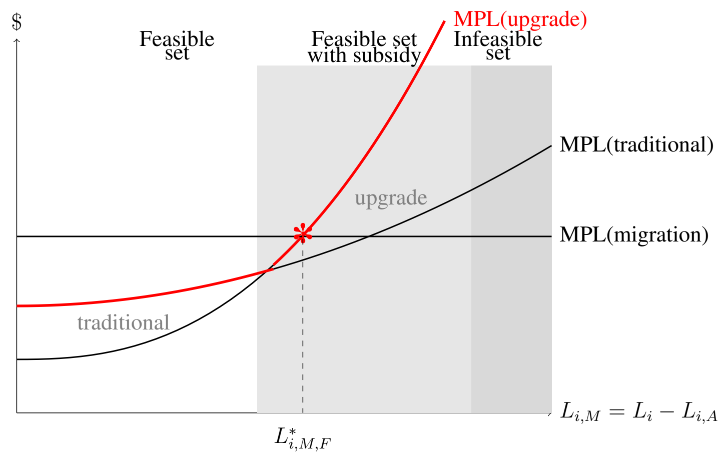


Figure B.2: Household decisions across upgrading and migration

Notes: This figure plots the inputs of the decision across upgrading and migration for the household. On the x-axis there is the number of labor units migrating ($L_{i,M}$) which is the number of labor units in the household net of the number of labor units in agriculture. On the y-axis, are the money equivalents. The left hand side of the graph is the feasible set for the household without any subsidy. The light-shaded areas reveal the levels of upgrading and migration that are made possible with when the input subsidy program is active. The ISP relaxes the credit constraint and allows for labor to migrate. Here the optimal level of migration is on that equates the marginal productivity of labor in migration and in the fertilizer intensive agriculture (upgrading).

C Structural estimation

Table C.1: Estimation of the parameters of the model

(1)	(2)	(3)
Par.	Year	Source and Sample
Migration		
w_i	2004	Idiosyncratic shock
m_v	2004	Absorbed in the area fixed effect
c_i	2004	Transportation cost to closest city
j_i	2004	Idiosyncratic shock
Production inputs		
L_i	2004	# HH members (including out-migrants)
F_i	2004	*Upgraders*: Fertilizer used
		Non-upgraders: computed from upgraders
A_i	2004	*Upgraders*: Estimated among upgraders
		Non-upgraders: computed using estimates for upgraders
Elasticities and outputs		
α	2004	Estimated among upgraders
β	2004	Estimated among upgraders
γ	2004	Estimated among non-upgraders
δ	2004	Estimated among non-upgrader
Y_i^T	2004	*Upgraders*: Computing using estimated δ, γ
		Non-upgraders: Using harvest data
Y_i^F	2004	*Upgraders*: Using harvest data
	2004	*Non-upgraders*: Computing using estimated α, β, γ
Number of households		
N_1	2004	# HHs in the area that received ISP
N^u	2004	# HHs with out-migrate in 2004
N^c	2004-8	Total HHs in area minus N^u
Prices and others		
p	2004	Price of maize in 2004
q_v	2004	Computed from Equation 11
C_v^F	2004	Absorbed in the area fixed effect
$\bar{F}_v$	2004	Total fertilizer used in area net of subsidy

Notes: This table summarizes the variables needed to estimate the model. Column (1) lists the parameters of the model. Column (2) lists the years from which the parameter data is taken. Column (3) details the variables used for each parameter.

Table C.2: Estimation of simultaneous Equations 18

	(1)	(2)	(3)	(4)	(5)	(6)
		Areas **with** subsidy			Areas **without** subsidy	
Variables	$\mathscr{D}_i$	$\mathscr{M}_i$	$L_{i,M}$	$\mathscr{D}_i$	$\mathscr{M}_i$	$L_{i,M}$
$\log(X_i)$	0.123***		0.123***	0.144***		0.136**
	(0.0116)		(0.0442)	(0.0208)		(0.0658)
$\log(q_v)$	0.827*		0.299	0.297		0.0673
	(0.431)		(0.184)	(0.683)		(0.230)
$\log(c_i)$	-0.0224		-0.178***	-0.0155		0.0187
	(0.0284)		(0.0453)	(0.0816)		(0.0637)
L_{iM}		0.161***			0.183***	
		(0.00433)			(0.00734)	
Y_T		-1.54e-08**			-2.45e-08**	
		(7.23e-09)			(9.70e-09)	
$(Y_F - Y_T) \times 1_{\mathscr{D}_i=0}$		-4.55e-09			-2.20e-08*	
		(1.04e-08)			(1.28e-08)	
$(Y_F - Y_T) \times 1_{\mathscr{D}_i=1}$		-1.79e-09			-1.49e-09	
		(1.93e-09)			(5.32e-09)	
q_v		7.98e-05*			6.01e-05	
		(4.08e-05)			(4.73e-05)	
c_i		-3.67e-07			7.82e-07	
		(6.74e-07)			(7.17e-07)	
$\log(A_i) \times 1_{\mathscr{D}_i=0}$			-1.121***			-0.759
			(0.418)			(0.476)
$\log(A_i) \times 1_{\mathscr{D}_i=1}$			0.0514			0.0398
			(0.0839)			(0.166)
$\log(P_v)$			-0.568***			-0.536*
			(0.216)			(0.284)
$\log(L_i)$.			2.447***			2.308***
			(0.0735)			(0.110)
$1_{FSP} \times \log(q_v)$			-0.0137			
			(0.0132)			
Constant	-5.028*	0.323***		-1.719	0.284***	
	(2.991)	(0.0535)		(5.328)	(0.0664)	
Area FE	Yes	No	No	Yes	No	No
Observations	1,495	1,495	1,495	580	580	580
R-squared	0.402	0.288	0.664	0.470	0.352	0.659

Notes: The table presents estimates of a system of simultaneous Equations 18 for areas that received the subsidy (columns 1-3) and those that did not (columns 4-6). The dependent variables are the binary decision to upgrade infrastructure ($\mathscr{D}i$), the decision to migrate ($\mathscr{M}i$), and the number of labor units migrating (L_{iM}). Standard errors are obtained with 300 bootstrap of all three steps of the estimation, i.e. the production function, the imputation of fertilizer and traditional production for farmers who did not respectively upgrade, and upgraded, and finally this joint decision.